DRAFT MOUNT GRAHAM RED SQUIRREL RECOVERY PLAN, FIRST REVISION

(*Tamiasciurus hudsonicus grahamensis*)

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Southwest Region
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Albuquerque, New Mexico

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Approved: ____DRAFT________________ Date: ___________

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U.S. Fish and Wildlife Service

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(*Tamiasciurus hudsonicus grahamensis*)

Prepared by:
Mount Graham Red Squirrel Recovery Team

Prepared for:
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Albuquerque, New Mexico

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The U.S. Fish and Wildlife Service is grateful for the donation of Dennis' original watercolor painting of the Mount Graham red squirrel, featured on the cover of this recovery plan.

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EXECUTIVE SUMMARY

Current Status: In 1987 the U.S. Fish and Wildlife Service (USFWS) listed the Mount Graham red squirrel as endangered with critical habitat, which contains an area designated as the Mount Graham Red Squirrel Refugium, as well as two additional peaks. The species' recovery priority is 6C, pursuant to the Endangered and Threatened Species Listing and Recovery Priority Guidelines (48 FR 43098 and 48 FR 52985). The Mount Graham red squirrel meets the species recovery priority 6C category due to its high magnitude of threat, low to moderate recovery potential, and conflict with construction or other economic activities. Population estimates climbed from approximately 140 individuals in the late 1980s to over 560 in the late 1990s. Subsequent habitat loss due to multiple insect outbreaks, wildfires, and fire suppression activities correlates with a decline in population estimates since that time. From 2001 through 2010, the population has fluctuated between approximately 200 and 300 squirrels.

Habitat Requirements and Limiting Factors: The primary limiting factor is habitat. This red squirrel historically inhabited only mature to old-growth associations in mixed conifer and spruce-fir above about 2,425 meters (m) (8,000 feet [ft]) in the Pinaleño Mountains of Graham County, Arizona. These mountains occur entirely on the Safford Ranger District of the Coronado National Forest, administered by the U.S. Forest Service (USFS). The red squirrel requires full, forested canopy cover for arboreal travel and some protection from aerial predation. The primary food of the red squirrel is conifer cones, so cone crops must be adequate. Several conifer species must be available in case one tree species' cone crop fails. Microclimates of cool, moist conditions near and at the base of large, mature, old growth conifers [the preference appears to be Engelmann spruce (*Picea engelmannii*), corkbark fir (*Abies lasiocarpa*), and Douglas-fir (*Pseudotsuga menziesii*) trees], along with large-diameter snags and dead and down logs, allow the red squirrel to create middens (deep piles of cone scales) and bury closed conifer cones to excavate and eat throughout the winter and into spring. Old growth trees can range between 100 to 300 years in age and are not easily replaced when lost. These trees have specific requirements on the mountain, which are increasingly difficult to meet due to recent drought, insect and disease damage, catastrophic wildfires, fire suppression activities, and predicted climate change. Devastating losses of trees have dictated changes in the red squirrel's opportunities for foraging, nesting, and dispersal, and the current habitat of the red squirrel is primarily in the mixed conifer forest rather than the spruce-fir.

Goal – The goal of this revised recovery plan is to assure the long-term viability of the Mount Graham red squirrel in the wild, allowing initially for reclassification to threatened status and, ultimately, removal from the List of Endangered and Threatened Wildlife.

Objective 1 – Restore and maintain sufficient Mount Graham red squirrel habitat to ensure the species' survival despite environmental stochasticity and the threat of climate change.

Criterion 1A (downlisting) – A mosaic of at least 70 percent of the range, or 5,600 hectares (ha) (13,838 acres [ac]), of the Mount Graham red squirrel meets the criteria for habitat, and management agreements among USFWS, Coronado National Forest, and Arizona Game and Fish Department (AGFD) are in place and being implemented to protect this habitat indefinitely. (Listing Factors A, D, and E)

Criterion 1B (delisting) – A mosaic of at least 80 percent of the range, or 6,400 ha (15,815 ac), of the Mount Graham red squirrel meets the criteria for habitat, and management agreements among USFWS, Coronado National Forest, and AGFD are in place and being implemented to protect this habitat indefinitely. (Listing Factors A, D, and E)

Objective 2 – Maintain a self-sustaining population of Mount Graham red squirrels sufficient to ensure the species' survival and address threats of predation, competition, vehicular mortality, small population size, genetic bottlenecking, and climate change.

Criterion 2A (downlisting) – There is statistical confidence (90 percent) that the rate of increase over a time of 10 years (5 generations) is 20 percent or greater of the known population, as measured by mountain-wide monitoring. (Listing Factors C and E)

Criterion 2B (delisting) – Once downlisting criteria are achieved, there is statistical confidence (90 percent) that the rate of increase over the following 20 years (10 generations) is increasing or stable, as measured by mountain-wide monitoring. (Listing Factors C and E)

Actions Needed: Actions required to ensure the stabilization and recovery of the Mount Graham red squirrel include:

1) protect and manage the remaining population and habitat,
2) restore and create habitat to allow for the existence of a viable and robust population,
3) research the conservation biology of the red squirrel with the objective of facilitating efficient recovery,
4) develop support and build partnerships to facilitate recovery, and
5) monitor progress toward recovery, practice adaptive management, through which the recovery plan and management actions are revised to reflect new information developed through research and monitoring.

Total Cost of Recovery (minimum): $2,919,000.00
Costs, in thousands of dollars:

Year	Minimum Costs: ($000s)
2010	567
2011	586
2012	586
2013	588
2014	592
2015+	To be determined

Date of Recovery:
The date of recovery for the Mount Graham red squirrel is unknown at this time. Habitat regeneration is a long-term process, several recovery actions will take at least 50 years to see results, and 100 to 300 years may be needed to fully restore red squirrel habitat. Time estimates for these actions are presented in the Implementation Schedule. Estimated time to delisting is contingent upon results obtained during the downlisting recovery period. Success in the creation and protection of habitat during the downlisting period will help determine the remaining effort necessary to reach recovery.

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PART I. BACKGROUND

The Endangered Species Act of 1973, as amended (Act), requires preparation of recovery plans for listed species likely to benefit from the effort. A recovery plan presents a set of recommendations endorsed by the U.S. Fish and Wildlife Service (USFWS). This plan was developed by the USFWS with direction and assistance from the Mount Graham Red Squirrel Recovery Team. This recovery plan for the Mount Graham red squirrel establishes recovery goals and objectives, describes site-specific recovery actions recommended to achieve those goals and objectives, estimates time and cost required for recovery, and identifies partners and parties responsible for implementation of recovery actions.

In the 1993 recovery plan for the Mount Graham red squirrel, the extent of the threats from insect and parasite infestations, subsequent drought, catastrophic wildfires, and fire suppression activities was not anticipated or sufficiently addressed. Their impact on the forest and the resulting decrease in squirrel habitat and increase in wildfire fuel in the Pinaleño Mountains, the only range in which the species occurs, was not considered or anticipated. These conditions, which greatly elevate threats to the Mount Graham red squirrel and its habitat, created the need to revise the 1993 Recovery Plan.

Brief Overview and Status Summary

On May 21, 1986, the USFWS published a proposed rule to designate the Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) as an endangered species, pursuant to the Act. On June 3, 1987, the USFWS published the final rule designating the species as endangered (52 FR 20994-20999) (USFWS 1987).

The 1987 final rule concluded that the Mount Graham red squirrel was endangered because its range and habitat had been reduced and its habitat was threatened by a number of factors, including the proposed construction of an astrophysical observatory, occurrences of forest fires, proposed construction and improvement of roads, and recreational development at high elevations. The rule concluded that red squirrels might also suffer due to resource competition with the introduced Abert's or tassel-eared squirrel (*Sciurus aberti*).

On July 14, 1988, the USFWS completed a biological opinion (BO), pursuant to section 7 of the Act, for the proposed astrophysical development in the Pinaleño Mountains and the Forest Management Plan. The Forest Management Plan was found to not jeopardize the continued existence of the Mount Graham red squirrel, but the proposed seven-telescope astrophysical development was found to jeopardize the species' existence. Three reasonable and prudent alternatives were described in the 1988 BO, but before the U.S. Forest Service (USFS) agreed to any alternatives, the Arizona-Idaho Conservation Act of 1988 (P.L. 100-696, November 18, 1988) was passed by Congress. It mandated that the USFS comply with a modified third alternative, which authorized the construction of three telescopes on Emerald Peak, the necessary support facilities, and an access road to the site, with minimization measures for reducing effects to the red squirrel. The law further required the University of Arizona (UA), with the concurrence of the Secretary of the Department of the Interior, to develop a management plan for the Mount Graham red squirrel. Construction of the four remaining telescopes will require

National Environmental Policy Act compliance and a new section 7 consultation with the USFWS.

The BO also called for the establishment of a 708-hectare (ha) (1,750-acre [ac]) Mount Graham Red Squirrel Refugium encompassing the largest contiguous stand of good to excellent red squirrel habitat, and containing the highest density of red squirrel middens on the mountain. The boundaries of the refugium were determined by examining maps with plots of known middens (at that time) that showed a dense concentration of middens in the Emerald, Hawk, and High peaks area. In that assessment, the 357 ha (882 ac) above 3,109 meters (m) (10,200 feet [ft]) in elevation held 136 middens and represented from 27 to 30 percent of the 502 squirrel carrying capacity predicted at that time for the Pinaleño Mountains. Because the area supported the largest contiguous stand of good to excellent habitat and the most middens, it was considered by the USFWS in their 1988 BO to be the core or refugium of the red squirrel population. The BO notes that the proposed critical habitat boundary (51 FR 18630) for the Hawk Peak-Mount Graham area was also to serve as the refugium boundary.

In 1993, the USFWS finalized the Mount Graham Red Squirrel Recovery Plan. By 2002, however, it was determined that the status of the red squirrel and the threats it faced had changed, and the USFWS reformed the Recovery Team to revise the 1993 Recovery Plan. This draft plan is the result of their work.

Currently, the Mount Graham red squirrel has a Recovery Priority Number of 6C. Pursuant to the Endangered and Threatened Species Listing and Recovery Priority Guidelines (48 FR 43098 and 48 FR 52985), a 6C classification indicates the taxon is a subspecies with a high magnitude of threat, low to moderate recovery potential, and conflict with construction or other economic activities. The threats currently thought to imperil the Mount Graham red squirrel population are detailed in Table 1.

Species Description and Taxonomy

The Mount Graham red squirrel likely represents a relictual population of what was once a much more widely distributed taxon. At the peak of the last glaciation (circa 18,000 years before present), pine and spruce forests were apparently present in the valleys of southeastern Arizona. Pollen spectra from late Pleistocene Lake Cochise (now Willcox Playa) are similar to current pollen spectra from pine and spruce forests at Deadman Lake (2,600 m [8,530 ft]) in the Chuska Mountains of northwestern New Mexico (Martin 1963). Beginning about 12,000 years before present, drying and warming trends were associated with the gradual isolation of coniferous forests to montane refugia (Betancourt *et al.* 1990). Over time, the distributions of red squirrels (Allen 1894) and other fauna now isolated atop southeastern Arizona mountain ranges likely tracked the increasingly limited and fragmented distribution of these forests.

Table 1. Direct and indirect threats to the Mount Graham red squirrel population and its habitat, including the Endangered Species Act listing factor[1], degree of threat[2], ability to manage the threat[3], and overall rank of importance of the threat[4].					
Threat (D=Direct or I=Indirect)	**ESA Listing Factor**[1]	**Degree of Threat**[2]	**Ability to Manage**[3]	**Column C x D**	**Rank**[4]
Climate (I)	A, E	4	5	20	1
Abert's squirrels (I)	E	4	4	16	2
Predation (D)	C	4	4	16	2
Insects (I)	A	4	4	16	2
Food availability (D)	A	4	4	16	2
Fire Suppression Activities (D/I)	A	4	4	16	2
Fire (D/I)	A	5	3	15	7
Small Population Size (D)	E	3	4	12	8
Disease (D)	C	1	5	5	9
Future Development (D/I)	A	3	1	3	10
Recreation (D/I)	A, E	2	1	2	11

[1] See Threats Assessment for a detailed discussion of each listing factor.
[2] Low (1) to High (5).
[3] High (1) to Low (5).
[4] Greatest threat with the least ability to manage that threat (1) to smallest threat with the greatest ability to manage that threat (11).

American red squirrels (*Tamiasciurus hudsonicus*) inhabit boreal, mixed conifer, and deciduous forests, ranging from the northeastern United States and Canada westward across North America to Alaska, and southward through the Rocky Mountain region into New Mexico and Arizona. There are 25 recognized subspecies in North America (Hall 1981). In the southern part of its range, the red squirrel is restricted to montane forests. This plan is for the Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*), the southernmost subspecies in North America.

The red squirrel is a small, grayish-brown arboreal (tree dwelling) rodent with a rusty to yellowish tinge along the back (Spicer *et al.* 1985). The tail is fluffy and the ears are slightly tufted in winter (Spicer *et al.* 1985). In summer, a black lateral line separates the upper parts from the white underparts. The cheek teeth number 16 (P1/1, M3/3), are low-crowned and tuberculate (with small knob-like processes), and the skull is rounded, with the postorbital process present (Hoffmeister 1986). The species ranges from 270-385 millimeters (mm) (10.8 – 15.4 inches [in]) in total length and from 92 – 158 mm (3.7 – 6.3 in) in tail length (Gurnell 1987). There are two recognized subspecies in Arizona: the Mogollon red squirrel (*T. hudsonicus mogollonensis*), which is found throughout northern Arizona; and the Mount Graham red squirrel, which is found only in the Pinaleño Mountains in southeastern Arizona (Brown 1986).

First described in 1894 by J. A. Allen, the Mount Graham red squirrel type specimen is from the Pinaleño Mountains, Graham County, Arizona. Allen (1894) designated it as a separate subspecies based on pelage (fur) differences and its isolation for at least 10,000 years from other red squirrel populations. The Mount Graham red squirrel is slightly smaller than the Mogollon red squirrel in body measurements, including total body, hind foot, and skull length (Hoffmeister 1986). The skull is also narrower postorbitally than that of *T. h. mogollonensis.* Hoffmeister (1986) found no sexual dimorphism in measurements of adult Mount Graham red squirrels. Based on measurements from ten specimens, Hoffmeister (1986) calculated an average total length of 331.5 mm (13.3 in), body length of 196.0 mm (7.8 in), and tail length of 135.5 mm (5.4 in). Average adult weight from nine specimens was 236.4 grams (g) (8.3 ounces [oz]) (Froehlich 1990).

Although Hoffmeister (1986) thought the subspecies was not strongly differentiated from the Mogollon red squirrel, he and Hall (1981) retained the subspecies designation. Research with both protein electrophoresis (Sullivan and Yates 1995) and mitochondrial DNA (Riddle *et al.* 1992), in conjunction with morphological and ecological considerations, demonstrates that the Mount Graham red squirrel is a distinct population that warrants subspecific status. The most recent survey of genetic variation in *Tamiasciurus* did not include *T. h. grahamensis* (Arbogast *et al.* 2001). However, genetic analysis recently conducted at the University of Arizona (Fitak and Culver 2009) demonstrated a reduced heterozygosity in Mount Graham red squirrels relative to the nearest populations of red squirrels in the White Mountains (*Tamiasciurus hudsonicus mogollonensis*). They found there is no migration between these two subspecies and that they are highly differentiated from each other. Additionally, Mount Graham red squirrel individuals had an average relatedness of over 90 percent, which nears the value of identical twins and could indicate potential impacts from inbreeding depression.

Population Trends and Distribution

Population Trends

Population size of the Mount Graham red squirrel throughout its range has been estimated and tracked since 1986 by an interagency team. Originally, the average occupancy rate for all middens was multiplied by the estimated number of middens on the mountain, 444, to yield an estimate of abundance for the red squirrel population (USFS 1988). In fall of 1990, different occupancy rates for each vegetation association (i.e., spruce-fir, transition, and mixed conifer forests) were used. Since then, more complete surveys have located additional middens (totaling 1,251 known locations in 2005). Therefore, population estimates before and after 1990 may not be comparable. Assumptions for both methods of estimating abundance are: (1) squirrel occupancy can be inferred from signs of recent caching and digging and from the condition of midden material, even when squirrels are not directly observed; and (2) one squirrel occupies only one active midden at a time. The red squirrel is highly territorial (C. C. Smith 1968), and the concept of one squirrel per midden is widely accepted and used for Mount Graham red squirrel management (Vahle 1978). Occasionally, conditions arise where more than one squirrel occupies a midden, or a Mount Graham red squirrel uses more than one midden (Froehlich 1990), but these are likely exceptions and usually seem to occur when food is extremely abundant or rare.

Until recent years, the highest densities of middens were located in the upper elevations supporting Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa*) (J. Koprowski, UA, unpubl. data). Midden surveys showed increasing numbers of Mount Graham red squirrels in both the spruce-fir and mixed conifer vegetation associations into 1998-2000, with peaks of over 560 individuals, after which the population declined. Population estimates dropped 42 percent in 2001 as compared to 1998-2000. However, population estimates from 2002-2009, which vary from 199 to 346, showed no obvious trend. Table 2 summarizes estimates of Mount Graham red squirrel populations throughout its range during 1986-2009.

The Mount Graham Red Squirrel Monitoring Program at the UA was established by the Arizona-Idaho Conservation Act of 1988 to monitor effects of the Mount Graham International Observatory (MGIO) on the Mount Graham red squirrel. As part of that program, Koprowski *et al.* (2005) monitored all middens in 252.2 ha (623.2 ac) surrounding the MGIO from 1989-2002. Middens were visited monthly from 1989-1996, and quarterly thereafter. Their study area contained 17.8 percent of all middens known in the mixed conifer forest and 66.9 percent of all middens known in the spruce-fir forest. From 1994-2002, the mixed conifer forest supported 54-83 middens within the study area, while the spruce-fir forest contained 120-224 middens. Abundance in the mixed conifer forest was relatively stable from 1994-2002; however, by 2002 only two occupied middens were found in the spruce-fir forest. Population declines in the spruce-fir forest corresponded with a period of insect damage and wildfires (including associated fire suppression activities) that began in 1996 and had devastated that forest type by 2002. Census data collected by the Mount Graham Red Squirrel Monitoring Program indicate a more dramatic decline than do the data of the interagency surveys (which have shown no discernible trend since Spring 2002 after a steep decline during 2001). The differences in results are likely due to differences of scale. The Mount Graham Red Squirrel Monitoring Program has focused on a subset of the mountain with pronouced impacts of fire and insect damage in the spruce-fir forest, whereas the multi-agency surveys sample the population rangewide.

Koprowski *et al.* (2005) characterized the decline of the Mount Graham red squirrel in their study area as catastrophic. They noted that in areas of high tree mortality in Alaska and Colorado, red squirrels did not completely disappear, but rather persisted in residual stands of trees where conditions remained suitable. The ability of the Mount Graham red squirrel to persist despite the current catastrophic decline is unknown; however, it apparently survived a similar situation in the late 1600s (Grissino-Mayer *et al*. 1995). Grissino-Mayer *et al.* (1995) sampled fire-scarred trees in four areas of the Pinaleño Mountains from Peter's Flat east to Mount Graham; the oldest trees in the spruce-fir forest were about 300 years old. They found evidence for a widespread, stand-replacing fire in 1685 that probably eliminated much of the forest atop the Pinaleño Mountains. The Mount Graham red squirrel survived this event, but its ability to persist after catastrophic habitat loss due to increasing threats such as global climate change and large, severe insect outbreaks is unknown. The squirrel may now face unprecedented conditions that could decrease the likelihood of population persistence (Koprowski *et al*. 2005). Koprowski *et al.* (2005) recommended management actions to increase available habitat and population size in the near and distant future.

Table 2. Mount Graham red squirrel population estimates (and confidence intervals) based on annual spring and autumn midden surveys. Estimates are derived from simple formulas (Appendix A) that use the percentage of active middens in each vegetation type found in a random sample and the known number of middens in each vegetation type.

Month/Year	Estimate		
	Conservative	Optimistic	Average
June 1986			323
October 1987			242
March 1988			207 (+/- 62)
October 1988	178 (+/- 62)	226 (+/- 62)	202
January 1989	116 (+/- 29)	167 (+/- 32)	142
April 1989	162 (+/- 15)	185 (+/- 15)	174
June 1989	116 (+/- 29)	167 (+/- 32)	142
October 1989	162 (+/- 15)	185 (+/- 15)	174
May 1990	132 (+/- 15)	146 (+/- 16)	139
October 1990	250	300	275
June 1991	259	293	276
October 1991	364	417	391
June 1992	354	399	377
October 1992	290	374	332
June 1993	223 (+/- 31)	417 (+/- 31)	320
October 1993	365 (+/- 22)	385 (+/- 22)	375
May 1994	357 (+/- 18)	372 (+/- 18)	365
October 1994	398 (+/- 11)	439 (+/- 11)	419
June 1995	283 (+/- 12)	352 (+/- 12)	318
October 1995	391 (+/- 12)	423 (+/- 12)	407
Spring 1996	292 (+/- 10)	323 (+/- 12)	308
Fall 1996	360 (+/- 12)	402 (+/- 12)	381
Spring 1997	356 (+/- 12)	376 (+/- 12)	366
Fall 1997	364 (+/- 12)	420 (+/- 11)	392
Spring 1998	462 (+/- 11)	492 (+/- 11)	477
Fall 1998	549 (+/-11)	583 (+/-11)	566
Spring 1999	562 (+/-12)	571 (+/-11)	567
Fall 1999	528 (+/-11)	531 (+/-11)	530
Spring 2000	516 (+/-11)	544 (+/-11)	530
Fall 2000	474 (+/-11)	493 (+/-11)	484
Spring 2001	326 (+/- 12)	362 (+/- 12)	344
Fall 2001	247 (+/- 12)	292 (+/- 11)	270
Spring 2002	288 (+/- 12)	346 (+/- 12)	317
Fall 2002	269 (+/- 8)	315 (+/- 8)	292
Spring 2003	224 (+/- 11)	245 (+/- 11)	235
Fall 2003	274 (+/- 13)	311 (+/- 13)	293
Spring 2004	284 (+/- 13)	295 (+/- 12)	290
Fall 2004	264 (+/- 12)	288 (+/- 12)	276
Spring 2005	214 (+/- 12)	235 (+/- 12)	225
Fall 2005	276 (+/- 12)	301 (+/- 12)	289
Spring 2006	199 (+/- 15)	214 (+/- 15)	207
Fall 2006	276 (+/- 12)	293 (+/- 11)	285
Spring 2007	216 (+/- 12)	230 (+/- 12)	223
Fall 2007	299 (+/- 11)	310 (+/- 11)	305
Spring 2008	297 (+/- 11)	305 (+/- 11)	301
Fall 2008	263 (+/- 11)	282 (+/- 10)	273
Fall 2009*	250 (+/- 11)	268 (+/- 11)	259
Fall 2010*	214 (+/- 12)	217 (+/- 12)	216

*As of Spring 2009, the Technical Subgroup of the MGRS Recovery Team determined that only Fall survey data will be taken. Analysis found that data acquired during Spring surveys are inconsistent due to the difficulty of detecting squirrels during this time of year (they are foraging far and wide and not yet caching cones), especially when compared to data collected during Fall surveys (when squirrels are actively caching cones, thereby making it much easier to determine if a midden is occupied).

Distribution

Found in the southernmost portion of the species' range, the Mount Graham red squirrel inhabits only the Pinaleño Mountains (Figure 1), which are entirely within the Safford Ranger District of the Coronado National Forest. The species inhabits upper elevation, mature to old-growth associations in mixed conifer and spruce-fir above approximately 2,425 m (8,000 ft). This habitat is now limited due to: drought; large-scale, stand-replacing, catastrophic wildfires (Clark Peak in 1996 and Nuttall Complex in 2004); fire suppression activities; and epidemics caused by four insect species that devastated the spruce-fir ecosystem on the mountain (1999 to present).

The majority of surviving red squirrels now occurs at lower elevations in the mixed-conifer forest that extend well down the mountain. Displacement from the spruce-fir to the mixed-conifer forest has resulted in closer association and likely more resource competition between the Mount Graham red squirrel and the introduced Abert's squirrel.

Historically, the Mount Graham red squirrel was common above 2,590 m (8,500 ft) (Spicer *et al.* 1985, USFS unpublished data). Midden surveys have located red squirrel middens at elevations as high as 3,268 m (10,722 ft) and as low as 2,353 m (7,720 ft) (Hatten 2009). This low-elevation midden was found on a north aspect of a gentle slope. The lowest observed elevation of a midden on a southward slope is 2,743 m (8,999 ft), and none have been observed on westward slopes below 2,670 m (8,760 ft) (Hatten 2009). Recently, a midden was found near the cabins in the Upper Turkey Flat summerhome area at approximately 2,286 m (7,500 ft) at the base of a mature Gambel oak (*Quercus gambelii*) (A. Casey, USFS, pers. comm. 2008). This midden is in a highly unusual location and is not thought to represent desireable habitat conditions for red squirrels. Currently, red squirrels most commonly inhabit areas between 2,438 m (8,000 ft) and 3,200 m (10,500 ft) due to recent changes in their habitat (T. Snow, Arizona Game and Fish Department [AGFD], pers. comm. 2007).

As recently as the 1960s, the species ranged possibly as far east as Turkey Flat and as far west as West Peak, but it is now only located as far west as Clark Peak. A local extirpation occurred on West Peak, possibly due to a fire in the mid-1970s that both isolated the West Peak subpopulation from the rest of the range and destroyed red squirrel habitat; however, anecdotal evidence suggests red squirrels may currently be present on West Peak, although this has not been confirmed (J. Koprowski, UA, pers. comm. 2008). Suitable habitat on West Peak is thought to currently exist (Hatten 2009), but no systematic surveys have been conducted there.

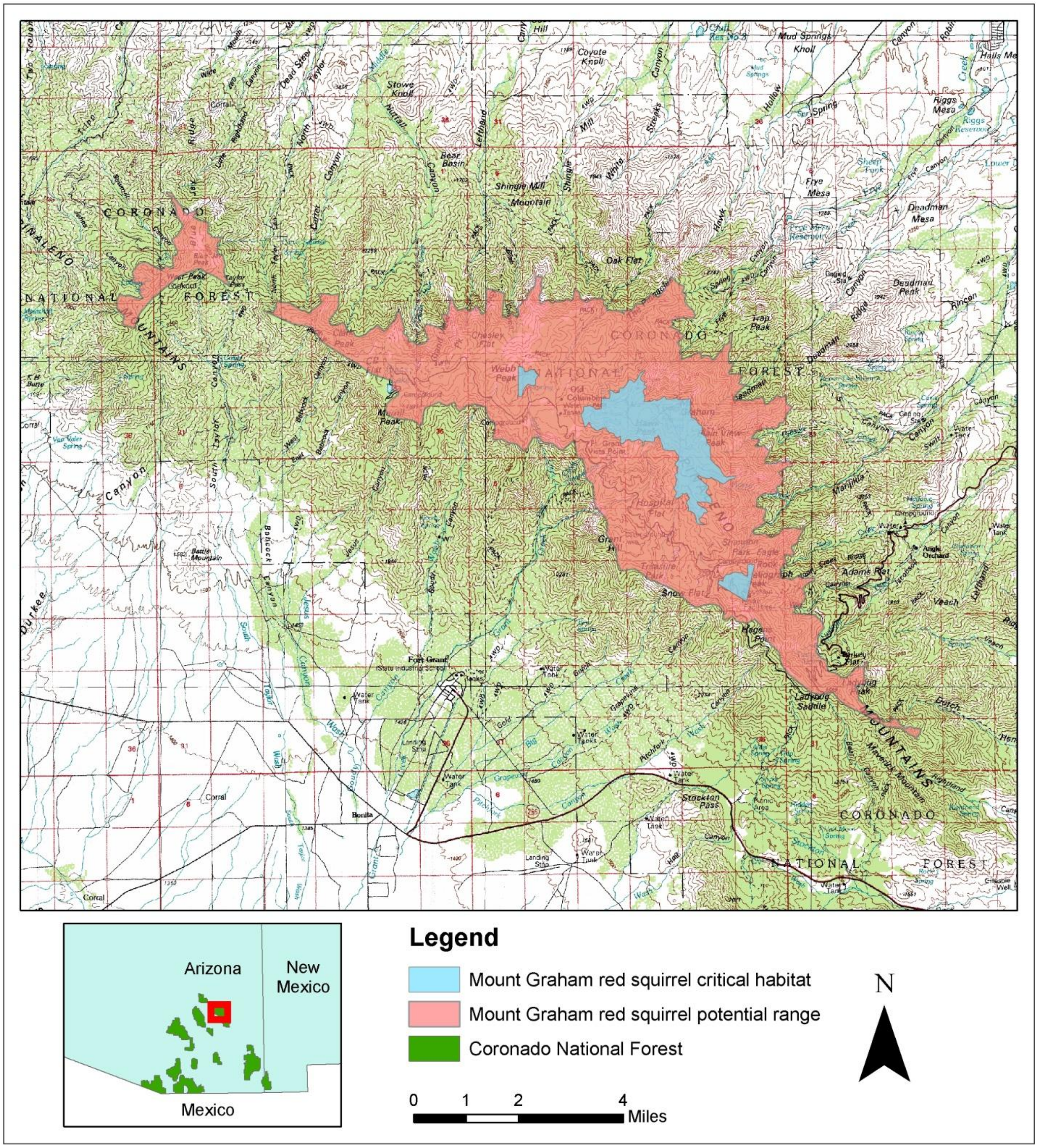

Figure 1. Mount Graham red squirrel potential range and critical habitat boundary, Pinaleño Mountains, Arizona (potential range boundary determined by Hatten 2009, Appendix C).

Life History and Ecology

Diet

Foods of the Mount Graham red squirrel include: (1) conifer seeds from closed cones, (2) above- and below-ground macro-fungi and rusts, (3) pollen (pistillate cones) and cone buds, (4) cambium of conifer twigs, (5) bones, and (6) berries and seeds from broadleaf trees and shrubs. Fledglings and eggs of birds, mice, young rabbits, carrion, juniper berries, oak acorns, aspen seeds, and ash seeds have been reported as food items for other subspecies of red squirrel (Warshall 1986). Each food is used seasonally: pollen and buds in the spring, bones by females during lactation, fungi in the spring and late summer, and closed cones low in lipids in the early summer. Closed cones high in lipids are stored for winter-time use (C. C. Smith 1968). Although population size and composition are influenced by many factors, the closed-cone seed crop seems to explain more red squirrel demography than any other single variable (Gurnell 1987). For red squirrels in general, conifer seed from stored, closed cones likely influences the length of the breeding season, number of adult females bearing two litters, number of adult yearling females that breed, longevity of adults, dispersal, diet switches, and perhaps the mean, long-term density of the population (M. C. Smith 1968, Rusch and Reeder 1978, Gurnell 1983, Halvorson 1986). Food availability also influences pre-implantation embryo losses (Millar 1970).

In the Pinaleño Mountains, red squirrels eat seeds and store cones from Englemann spruce (*Picea engelmannii*), white fir (*Abies concolor*), Douglas-fir (*Pseudotsuga menziesii*), corkbark fir (*Abies lasiocarpa*), and southwestern white pine (*Pinus strobiformis*). Midden surveys in the Pinaleños indicate that seeds of Engelman spruce, corkbark fir, Douglas-fir, and southwestern white pine are the main food resource for the Mount Graham red squirrel (Rushton *et al*. 2006). Use of ponderosa pine (*Pinus ponderosa*) seeds or caching ponderosa pine cones by the Mount Graham red squirrel is extremely limited, probably due to microclimate considerations. Cone caching and consumption of cone seeds by red squirrels have been reported in more northerly latitudes (Hatt 1943, Finley 1969, Ferner 1974). Douglas-fir, generally a consistent cone producer (Finely 1969), is important in the Pinaleños, especially in areas where it co-exists with Engelmann spruce. It is likely increasingly important in years when the spruce cone crop fails but Douglas-fir still produce adequate numbers of cones, such as in 1987, 1988, and 1989. Douglas-fir is a more widespread species in the Pinaleño Mountains than Engelmann spruce, but also is more often found in logged and patchy areas at lower elevations where microclimates to support middens may not be as suitable as at higher elevations. This may reduce its overall contribution to the food supply of red squirrel populations. The number of mature seed trees per territory necessary to supply the red squirrels' food requirements in the Pinaleño Mountains has not been determined. As nutritional values of seeds from different conifer species in the Pinaleños vary seasonally and by tree species (Miller 1991), diversity in the red squirrel's diet might be important both nutritionally and in terms of offering options when preferred sources run low.

Tamiasciurus hudsonicus in British Columbia ate 42 different species of fungi, with a preference for small false truffles (C. C. Smith 1968). In two examples, mushrooms and false truffles supplied more than half the squirrels' daily calories. Ferron and Prescott (1977) observed red squirrels spending up to 20 percent of their time harvesting fungi in season. By volume, fungi were 77 percent of red squirrels' diets in western Oregon (Maser *et al.* 1978). Mount Graham red squirrels readily consume false truffles and other fungi, which appear during spring snowmelt and after summer rains begin (Brown 1986, Froehlich 1990). Those not eaten may be dried and stored (Brown 1986). Miller (1991) analyzed the nutritional content of the three above-ground species of mushrooms eaten by Mount Graham red squirrels. Percent crude protein and percent digestible protein were higher than all conifer seeds except Engelmann spruce in summer (Miller 1991). Truffle protein content also was as high as some conifer seeds per unit weight (C. C. Smith 1968). Mushrooms and truffles may take less effort to eat than extracting seeds from cones. Combined with information on nutritional values, this may explain in part the relative importance of fungi in the diet.

Home range

Mount Graham red squirrels create one or more middens within their home range, which are areas that consist of piles of cone scales in which squirrels cache live, unopened cones as an over-wintering food source. Placement of these middens tends to be in areas with high canopy closure near food sources (e.g. Douglas fir, corkbark fir, and Engelmann spruce). This type of placement allows specific moisture levels to be maintained within the midden, thereby creating prime storage conditions for cones and other food items, such as mushrooms, acorns, and bones. They also seem to prefer areas with large snags or downed logs that provide cover and safe travel routes, especially in winter, when open travel across snow exposes them to increased predation. There appears to be no differentiation in selection of midden sites based on sex (Alanen *et al*. 2009). Wood *et al*. (2007) used satellite imagery to examine three different-sized areas around middens to determine which size best predicted use by Mount Graham red squirrels when compared to randomly selected locations. They chose a 10 m (33 ft) buffer distance to mimic previous field studies (Smith and Mannan 1994, Koprowski *et al*. 2005) and to reflect microclimate conditions at the midden. They also selected 28 m (92 ft) and 56 m (184 ft) buffers to represent the smallest and largest known red squirrel territories reported in the literature (Steele 1998) to evaluate whether midden sites are selected at a larger scale. They identified that site selection best occurred on a 28 m (92 ft) plot around middens, with strong selection on 56 m (184 ft) plots as well, indicating that selection also occurs on a territory scale rather than only at a microclimate level at the midden site. Site selection for middens at both the 28 m (92 ft) and 56 m (184 ft) scale was more likely to be located in areas with a high number of healthy trees and correspondingly high seedfall.

Vahle (1978) noted the importance of single, mature, old growth Douglas-fir trees in home ranges of red squirrels in the White Mountains, Arizona, but also stated that at least 9 to 14 mature seed trees within a red squirrel's home range (average 0.40 ha [1.2 ac]) ensured an adequate food supply. In general, large, dominant trees are the best cone producers. Red squirrels usually concentrate their cone cutting for winter storage on the few trees in a stand that are the best cone producers (Finley 1969). Froehlich (1990) found that Mount Graham red squirrels tended to concentrate foraging bouts on the few productive trees within a squirrel's home range (average 3.62 ha [8.9 ac]). Mean diameter at breast height (dbh) of these "forage trees" was significantly larger than other adult trees of the same species within the home range (Froehlich 1990).

Recent research on the home-range sizes of Mount Graham red squirrels (in which they spend 95 percent of their time) indicates they are 3 to 10 times greater than reported for other populations of red squirrels (Koprowski *et al*. 2008), annually averaging 2.4 ha (5.9 ac) for females and 9.9 ha (24.5 ac) for males (Koprowski, draft MGRS Recovery Team Meeting Minutes, March 16, 2006). Core areas, or areas where individuals spend 50 percent of their time, annually average 0.7 ha (1.7 ac) for females and 2.8 ha (6.9 ac) for males (Koprowski, draft MGRS Recovery Team Meeting Minutes, March 16, 2006). Both males and females can be found farther from their middens in summer than in any other season. Male Mount Graham red squirrels maintain discrete core areas in all seasons except for summer (when they likely are looking for scarce females). Female Mount Graham red squirrels, on the other hand, minimize overlap throughout their home-range during all seasons. The expansion of red squirrel home ranges in summer is perhaps because during fall, winter, and spring, the squirrels need to invest energy in defending their middens where food supplies are concentrated. In summer, cached food stocks are depleted and new, widely dispersed, food sources (such as mushrooms and ripening cones) become available, which, along with mate searching, could explain some of the increases in range size during this time of year (Koprowski *et al*. 2008).

Reproduction

Seasonality of reproduction for both male and female Mount Graham red squirrels is similar to that of other red squirrel populations in coniferous forests of northern and western North America (Steele 1998, Koprowski 2005a). In most populations studied, red squirrels breed from February through early April. Individuals of some populations have begun breeding in January (Layne 1954) and two breeding seasons per year have been reported in a few populations (Layne 1954, C. C. Smith 1968, Millar 1970, Lair 1985), including the populations in central Arizona (Uphoff 1990). One female Mount Graham red squirrel produced two litters in one year (Froehlich 1990), but the percentage of females that produce two litters per year is unknown. The triggering mechanism for the onset of breeding is not well understood, but has been related to the quality and quantity of the spring bud crop on conifers (Lair 1985).

Female red squirrels have only one day of fertility during each breeding period (Flyger and Gates 1982), and the gestation period for red squirrels is 35 to 40 days (Woods 1980). Compared to other red squirrels, female Mount Graham red squirrels on average give birth to fewer young (reported means = 2.35 and 2.15 for Mount Graham red squirrels; 3.69 and 3.72 for other red squirrels) (Rushton *et al*. 2006 and Munroe *et al*. 2009, respectively). Typical of many tree squirrels, first reproduction for male and female red squirrels occurs after their first winter (Gurnell 1987). After the second winter, all squirrels are considered adults. The proportion of yearling and adult squirrels that breed varies widely from year to year and appears to be crudely related to seed crop availability (reviewed in Gurnell 1987). Rusch and Reeder (1978) and Wood (1967) found "yearling" reproductive rates (number of yearling females producing young) varied from 24-88 percent. Rates for yearlings were always lower than for older females. The proportion of adult females that produces two litters per year is likely to be highly variable.

Constructed in natural hollows or abandoned cavities made by other animals, such as woodpeckers, squirrel nests can be in a tree hollow, hollow snag, downed log, or among understory branches of a sheltered canopy. Froehlich (1990) found that Mount Graham red squirrels built 60 percent of their nests in snags, 18 percent in hollows or cavities in live trees, and 18 percent in logs or underground. Only four percent of nests were bolus grasses built among branches of trees. Slightly different proportions were found by Morrell *et al*. (2009), who noted 67 percent of the red squirrel nests within their study area were located in tree cavities, 27 percent were bolus nests, and 7 percent were ground nests. Leonard and Koprowski (2009) found that Mount Graham red squirrels appear to favor cavity nests over bolus nests (also called dreys), whereas the nearest population of red squirrels in the White Mountains, the Mogollon red squirrel, used predominantly dreys. They speculate that localized processes such as slightly elevated temperatures and isolation may be responsible for the disparity between these two subspecies. In the Pinaleño Mountains, snags are important for cone storage as well as nest location; both nests and stored cones have been found in the same log or snag. Once occupied, nests are often enlarged by squirrels and can be anywhere from 0 m to over 610 m (2,000 ft) away from the midden (Red Squirrel Monitoring Program, unpub. data).

Survivorship

Trends in age-specific red squirrel survivorship demonstrate a classic mammalian Type III survivorship curve (Steele 1998) in which mortality is >60 percent during the first year of life, about half that rate during the second year of life, followed by relatively high survivorship and constant mortality through the adult years (Kemp and Keith 1970, Davis and Sealander 1971, Rusch and Reeder 1978, Halvorson and Engeman 1983, Erlien and Tester 1984). Maximum longevity for the red squirrel in the wild is reported to be 10 years (Walton 1903) and 9 years in captivity (Klugh 1927), although 3-5 years is more typical (Munroe *et al*. 2009). Annual adult mortality of Mount Graham red squirrels appears to be higher than for red squirrels throughout North America (47 percent vs. 34.73 percent) (Rushton *et al*. 2006). Annual juvenile mortality has not been studied directly, but Munroe *et al*. (2009) suggest it could be higher than other populations of red squirrels due to the extreme natal dispersal distances required to establish a new territory. The survivorship of squirrels in insect-damaged, spruce-fir habitat is less than the survivorship of squirrels in undamaged, mixed-conifer habitat, leading to a 50 percent reduction in potential breeding events of Mount Graham red squirrels in the insect-damaged versus undamaged habitat (Zugmeyer 2007).

Predation

Studies of radio-collared animals suggest that predation accounts for a majority of the mortality in red squirrels (Kemp and Keith 1970, Rusch and Reeder 1978, Stuart-Smith and Boutin 1995a, 1995b, Kreighbaum and Van Pelt 1996, Wirsing *et al.* 2002). However, the availability of alternative prey for predators (Stuart-Smith and Boutin 1995b), availability of food for red squirrels (Halvorson and Engeman 1983, Wirsing *et al.* 2002), and variation in habitat use by individual squirrels (Larsen and Boutin 1994) have been suggested to predispose some animals to higher susceptibility to predation. Up to 75 to 80 percent of the mortality experienced by Mount Graham red squirrels appears to be due to predation, most of which is caused by raptors (Koprowski, draft MGRS Recovery Team Meeting Minutes, March 16, 2006).

Avian predators likely to prey on Mount Graham red squirrels are goshawks (*Accipiter gentilis*), red-tailed hawks (*Buteo jamaicensis*), Mexican spotted owls (*Strix occidentalis lucida*), great horned owls (*Bubo virginianus*), and Cooper's hawks (*Accipiter cooperii*) (USFS 1988, Schauffert *et al.* 2002). On Mount Graham, Kreighbaum and Van Pelt (1996) reported that four juveniles were killed by raptors during natal dispersal. A Mexican spotted owl also killed a juvenile red squirrel near the natal nest (Schauffert *et al.* 2002). From June 2002 until July 2004, avian predators accounted for >60 percent of 30 mortalities on radiocollared adult Mount Graham red squirrels (J. Koprowski, UA, unpubl. data).

Mammalian predators (Hoffmeister 1956, USFS 1988) in the Pinaleño Mountains at elevations where they would potentially prey upon Mount Graham red squirrels include mountain lion (*Puma concolor*), black bear (*Ursus americanus*), bobcat (*Lynx rufus*), coyote (*Canis latrans*), and gray fox (*Urocyon cinereoargenteus*). On Mount Graham, a bobcat was observed stalking a red squirrel (Schauffert *et al.* 2002) and a gray fox was observed capturing an adult female red squirrel (24 Feb 2003, J. Koprowski, UA, unpubl. data). From June 2002 until July 2004, mammalian predators accounted for >13 percent of 30 mortalities on radiocollared adult Mount Graham red squirrels (J. Koprowski, UA, unpubl. data)

Little is known about predation on red squirrels by reptiles; however, one animal was taken by a timber rattlesnake (*Crotalus horridus*) (Linzey and Linzey 1971). In the nearby Chiricahua Mountains, gophersnakes (*Pituophis melanoleucus*) climb and inspect nests of Chiricahua fox squirrels (*Sciurus nayaritensis chiricahuae*) within the pine-oak belt (Kneeland *et al.* 1995) and could depredate an occasional red squirrel in the Pinaleño Mountains.

Habitat Characteristics

Habitat for Mount Graham red squirrels depends on the ability of the forest to produce reliable and adequate conifer cone crops for food as well as microclimatic conditions suitable for storage of closed cones. These conditions have been met for western red squirrels in mature to old-growth stands that have closed canopies (Finley 1969, Vahle 1978, Smith and Mannan 1994), which may increase fungal food supplies. Other elements that increase the quality of habitat are downed logs, snags, and interlocking branch networks (Froehlich 1990, Smith and Mannan 1994). These habitat characteristics provide red squirrels with adequate food resources; perching, storage and nesting sites; runways that allow cone retrieval in the winter; and escape routes for avoidance of predators (C. C. Smith 1968, Vahle 1978).

The following description of nest site and midden selection is taken from "Pine Squirrel (*Tamiasciurus hudsonicus*): a technical conservation assessment" (Koprowski 2005b):

> "Nest site selection is important for thermoregulation, cone and fungal storage, and predator avoidance (Hatt 1929, Layne 1954, C. C. Smith 1968, Rothwell 1979, Fancy 1980). Cavities in snags or decadent logs are commonly used and may be preferred to other nest types for they are commonly used by red squirrels in the eastern portion of their range (Hamilton 1939, Layne 1954). In coniferous and mixed forests, cavities may be limiting, and nests constructed of leaves (also termed dreys) (Rothwell 1979, Fancy 1980, Young *et al.* 2002) and underground burrows (Hatt 1929, Yahner 1980) are most often used. Nest sites are typically in stands of trees with large diameter and significant

canopy closure and interdigitation with adjacent trees (Rothwell 1979, Fancy 1980, Vahle and Patton 1983, Young *et al.* 2002).

Midden sites require cool temperatures and moist environs for optimal storage of cones (Shaw 1936, C.C. Smith 1968, Finley 1969). In spruce-fir and mixed forests of Arizona, red squirrel midden sites exhibit high canopy closure, high foliage volume, numerous decadent logs, many standing snags, and high stem density relative to random sites (Vahle and Patton 1983, Smith and Mannan 1994). Territories are usually centered around middens likely because they contain one to two years of cone resources (C.C. Smith 1968, Gurnell 1984) and are critical to red squirrel survival (M.C. Smith 1968). Territory size appears to be determined in large part by the energetics of cone acquisition (C.C. Smith 1968, 1981). Territory sizes across a wide variety of forest types typically are less than 1 ha (Gurnell 1987, Munroe *et al.* 2009). Territory size increases markedly during years of food shortage (M. C. Smith 1968) or in suspected marginal habitat (Kreighbaum and Van Pelt 1996, Munroe *et al.* 2009).

The ability of red squirrels to use a diversity of forest types (Layne 1954, Steele 1998) suggests that many forest mosaics may provide habitat. The primary landscape feature that appears to limit red squirrel use of forest landscapes is fragmentation by any stand replacement agent including harvest, fire, or insect-induced mortality. The resulting isolation of stands appears to be one means by which fragmentation influences red squirrels. Red squirrels often range out to 1 km from their territory (Larsen and Boutin 1994) and demonstrate a strong homing instinct (Bovet 1984, 1991); however, edge habitats appear to be avoided (Cotterill and Hannon 1999). Thirty-nine percent of translocated animals crossed gaps to return to their home territory if the gap was relatively short compared with alternative routes. This result illustrates the complexities of habitat fragmentation (Bakker and Van Vuren 2004). On a range-wide basis, small fragments of habitat tend to have high densities of red squirrels (Koprowski 2005c). Such findings suggest that forest mosaics that maintain canopy cover over continuous areas provide habitat for red squirrels (Carey 2001)."

Due to changes in red squirrel habitat through insect outbreaks and fire, Hatten (2009) developed a spatially explicit habitat model that could identify Mount Graham red squirrel habitat remotely with satellite imagery and a Geographic Information System (GIS) and that could detect changes in habitat among years. In this study, a boundary surrounding approximately 8,000 ha (19,768 ac) was calculated, encompassing all areas in the Pinaleño Mountains within which Mount Graham red squirrel habitat potentially could exist. The boundary includes all areas on the mountain above 2,744 m (9,000 ft), including West Peak (an area where squirrels resided historically, but no longer exist) and areas down to 2,353 m (7,720 ft) on the northern and eastern slopes of the mountain. Within this boundary, areas are considered habitat if they meet the following conditions:

1) They are within the mixed conifer, ecotone, and spruce-fir series AND
2) They are above 2,744 m (9,000 ft) OR
3) If they are below 2,744 m (9,000 ft), they meet the following criteria:

a. > 2,353 m (7,720 ft) elevation
b. north or east aspect
c. < 45-degree slope

Based on these criteria, Hatten classified red squirrel habitat with 93 percent accuracy and non-habitat with 83 percent accuracy. He determined 5,365 ha (13,257 ac) of habitat existed in 1993 (approximately 67 percent of the area within the 8,000 ha boundary), which is near the time of listing (1987) and prior to the insect outbreaks and Clark Peak and Nuttall Complex Fires. By comparing the 1993 image to images taken in 1997 (after the Clark Peak Fire) and 2003 (after and during the insect outbreaks), he determined the Clark Peak Fire accounted for a reduction in habitat of approximately 3.2 percent, whereas the insect outbreaks accounted for another 4.8 percent decrease, reducing available habitat to approximately 4,936 ha (12,197 ac). In a more recent analysis using satellite imagery from June 2008, it appears that only 2,601 ha (6,427 ac) of Mount Graham red squirrel habitat currently exist in the Pinaleño Mountains, representing a 52 percent loss of habitat since 1993 (Hatten, unpub. data). This further reduction in habitat is due primarily to the Nuttall Complex Fire that occurred in 2004.

Geography

The Pinaleño Mountain Range is in the Basin and Range geographic province of southeastern Arizona, which is composed of dispersed mountain ranges separated by desert and grassland valleys. The Pinaleño Mountains could be considered a northern outlier of the often isolated mountains associated with Sierra Madre Occidental of Mexico; such mountain ranges or sierras are commonly referred to as the Madrean Archipelago (e.g., DeBano *et al.* 1995) or Sky Islands (Heald 1967). The Pinaleño Mountains are the most northeastern of the larger Arizona Sky Islands and lie just south of the Gila River. To the north of the Gila River are mountains belonging to the Rocky Mountain (Petran) complex, which are geographically very close, but have never been connected to the Pinaleños (Davis 1995). The Pinaleños contain the highest point in southern Arizona (Mount Graham [High Peak], at 3,267 m [10,720 ft] above sea level) with an elevational gain of 2,048 m (6,720 ft) from its base to the summit (Johnson 1988). This is the highest altitudinal spread of any Arizona mountain range.

Climate

The Basin and Range Province of southeastern Arizona is typified by two rainy seasons: summer and winter. Summer rains, most of which occur in July and August in the form of afternoon thundershowers, are spawned by monsoons originating from the American tropics. Although these storms tend to be sporadic and spotty, they may produce large amounts of rain and cause localized flooding. By contrast, winter rains tend to be less severe, but longer in duration. The amount of rainfall varies greatly by elevation and microclimatic factors. In the Gila Valley, rainfall averages about 20 cm (8 in) (Turner and Brown 1994), but the spruce-fir forests above about 2,450 m (8,038 ft) may receive up to 100 cm (39 in) or more, including precipitation in the form of snow (Pase and Brown 1992).

Temperatures vary greatly depending on season and elevation. At the Columbine Visitor's Center (2,926 m [9,600 ft]), temperatures can range from highs around 30 ºC (86 ºF) in the summer to lows around -20 ºC (-4 ºF) in the winter (http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?azACOL, accessed 30 September 2008).

Plant Associations

Lists of plant taxa for the Pinaleño Mountains can be found in Johnson (1988), McLaughlin (1993), and McLaughlin and McClaran (2004). For purposes of this recovery plan, only the plant associations used by the Mount Graham red squirrel are discussed below.

Petran and Madrean Montane Conifer Forests.— These biotic communities are primarily composed of mixed conifers, belonging to two basic types: "ponderosa pine" forests and Douglas-fir/white fir dominated forests (Pase and Brown 1994). There is a great deal of hybridization or hybrid-derivatives in the large, mid-elevation pines (Rehfeldt 1999), which include ponderosa pine (*Pinus ponderosa* var. *scopulorum*), Arizona pine (*P. ponderosa* var. *arizonica*), and perhaps Apache pine (*Pinus engelmannii*). In the Pinaleño Mountains, there are three phenotypes (groups of individuals exhibiting the same physical traits) of the ponderosa pine group. There is not a well-developed elevational band of these large pines in the Pinaleños, due to steep slopes and microclimatic factors. The ponderosa pine forest is the "transition zone" of Merriam (1890, 1898) at elevations between 1,981 m to 2,438 m (6,500 ft to 8,000 ft).

Douglas-fir/white fir-dominated forests are well represented in some areas, but are somewhat spotty across the mountain range. Both of these species also can be found mixed with other forest types as co- or sub-dominants. The Douglas-fir/white fir biotic community is equivalent to the "Canadian life zone" of Merriam (1890, 1898), at elevations between 2,438 m to 2,896 m (8,000 and 9,500 ft).

Petran Subalpine Conifer Forest.—In the Madrean Archipelago, this biotic community is only known from the Chiricahua and Pinaleño mountains (Pase and Brown 1992). In the Pinaleños, the highest peaks support, almost exclusively, Engelmann spruce and corkbark fir, with intrusions of quaking aspen (*Populus tremuloides*) and southwestern white pine. The Pinaleños possess the only Engelmann spruce/corkbark fir forests in the Madrean Archipelago (McLaughlin 1993), but this forest type is also found in some areas north of the Gila River in Arizona. The Petran subalpine conifer forest is known as the "Hudsonian life zone" of Merriam (1890, 1898), and is found at elevations of about 3,000-3,267 m (9,500 ft to 10,720 ft) in the Pinaleño Mountains. At the lower elevations, it is typically found in north-facing canyons and slopes. This community has been devastated by drought, insect damage, tree disease, and fire from 1996 to 2010.

Riparian Zones.—Riparian zones can occur in any biotic community. During non-drought years, the Pinaleños have eight perennial streams (Johnson 1988) and numerous ephemeral streams. In 2004 and 2005, Grant Creek and Wet Creek had perennial flow, but some other creeks that normally flow year-round were dry or reduced to pools during low-flow periods. Lower elevation riparian areas feature species such as Fremont cottonwood (*Populus fremontii*), netleaf hackberry (*Celtis reticulata*), and desert willow (*Chilopsis linearis*). Riparian stands in pine-oak woodlands and Douglas-fir forests have a number of showy, deciduous trees, including box elder

(*Acer negundo*), bigtooth maple (*A. grandidentatum*), Arizona sycamore (*Platanus wrightii*), velvet ash (*Fraxinus velutina*), and Arizona walnut (*Juglans major*).

Succession and the Fire Cycle

Several drivers can initiate succession in the Sky Islands, including volcanism, erosion, insect outbreaks, fire, and weather events (e.g., flood, mudslides, wind-throw, and ice-storms). The most prevalent historically was frequent, low-intensity wildfire (Ffolliott *et al.* 1996). Lighting-caused wildfires most often occurred during the arid pre-monsoon season (late April through late June) (Swetnam and Baisan 1996). Lower elevations generally burned at a higher frequency than higher elevations, although the fire history on Mount Graham is an example of where the relatively high-elevation mixed-conifer forest had a fire frequency similar to lower elevation pine forests (Grissino-Mayer *et al*. 1995). Prior to the introduction of heavy livestock use, semidesert grasslands and oak woodlands could burn every 4 to 10 years (McPherson 1995, Allen 1996, Robinett and Barker 1996, Payson *et al.* 2000). Surface fires were quite common in nearly all montane forest types prior to about 1900, with a maximum fire-free interval between fires of approximately 8 to 23 years (Swetnam and Baisan 1996). Livestock overgrazing, which began in earnest in the late 1800s, reduced fine fuels, inhibiting the low-intensity and frequent spread of wildfire. Active fire-suppression efforts were initiated early in the last century, which again reduced wildfire intensity, frequency, and spread (Allen 1996), especially in forests.

By examining fire-scarred logs, pieces of wood, snags, and living trees, Grissino-Mayer *et al.* (1995) assembled a fire history of the Pinaleño Mountains above 2,750 m (9,000 ft) for the period from 1584 to 1993. During the pre-European settlement era (before 1880), low-intensity surface wildfires occurred once every four to six years in the mixed-conifer forests, which at that time were relatively open and, between the trees, supported many species of grasses that formed fine fuels to carry ground fires. In this time, wildfires typically burned in late spring and early summer before the onset of the summer rains. The mixed-conifer zone acted as a fire buffer for the spruce-fir forest in that ground fires would typically move through the understory of the mixed-conifer forest and then stop at the more mesic spruce-fir forest. Only during times of severe drought did wildfires extend into the spruce-fir forest, where the frequency of major stand-replacing fires in the western United States likely ranged from one to many centuries (Grissino-Mayer *et al*. 1995, Arno 2000, Schoennagel *et al*. 2004). The actual fire frequency in the spruce-fir forest in the Pinaleño Mountains is unknown; however, Grissino-Mayer *et al.* (1995) present evidence that the last historical stand-replacing wildfire in the spruce-fir forest occurred in 1685. They found no spruce or fir older than 300 years of age, and Douglas-fir in the mixed conifer/spruce-fir transition zone exhibited heavy damage at that time. Occurrence of stand-replacing fire likely has substantial adverse effects to Mount Graham red squirrel habitat and squirrel population viability. However, the ability of the squirrel to survive such events, and the areal extent and frequency at which such fires are compatible with long-term persistence of the Mt Graham red squirrel, are unclear.

Fire scars were largely absent from mixed-conifer forests after about 1880. Grissino-Mayer *et al.* (1995) attributed that absence to livestock grazing that removed fine fuels, and more recently, effective fire suppression (USFS 1986, as amended). Absence of ground fires allowed a buildup of woody fuels that increased the likelihood of infrequent but intense crown fires (Grissino-

Mayer *et al*. 1995, also see Swetnam and Baisan 1996, Danzer *et al.* 1997). These conditions led to the April 1996 Clark Peak wildfire, which burned 2,718 ha (6,716 ac) in the Pinaleño Mountains. Since 1999, conditions have been exacerbated by drought and multiple insect infestations, including bark beetles, moth caterpillars, and a non-native aphid that has killed most of the Engelmann spruce in the subalpine forest. During the summer of 2004, the Nuttall Complex wildfire and associated suppression activities burned approximately 11,736 ha (29,000 ac) in the Pinaleño Mountains, including portions of subalpine forest where trees had been killed by insects and drought. Fire suppression activities during recent catastrophic wildfires have limited the extent of fire damage on Mount Graham and in Mount Graham red squirrel habitat; however, in some cases backfires set to halt the spread of a wildlfire have burned significant acreage of habitat. In many cases, these areas would have been burned by the oncoming wildfire, but it is often difficult to separate the effects of the fire from that of the suppression activities.

Because the typical, low-intensity, frequent ground wildfire cycle was interrupted, fuel loads and successional patterns have changed in each of the biotic communities within the range of the Mount Graham red squirrel. Montane meadows have been invaded by a number of shrubby species, reflecting the change from moist to dry soils and lack of natural fire. The shrubs are then replaced by trees, thereby changing the community from meadow to forest, along with a concomitant reduction in the number of species. This pattern occurs from the forest edges of the meadows and progresses toward the interior of the meadow. Madrean evergreen woodlands are more densely stocked than they were historically during a more typical wildfire cycle, with fewer open, grassy spaces; herbaceous growth is often insufficient to carry ground fires through these densely stocked stands (Kruse *et al.* 1996). Ponderosa pine forests also are more densely stocked with smaller diameter trees (Fulé and Covington 1995). Drought and pathogenic, multiple-insect activity have resulted in a stand-replacing event for Engelmann spruce in the highest elevations of the Pinaleños, an expected outcome of subalpine forest climax (Stromberg and Patten 1991). Catastrophic insect outbreaks are important factors in succession in the Pinaleño Mountains (e.g., Negron *et al.* 2000) and are more fully discussed in the Threats Assessment.

One outcome of these successional changes in plant communities is a change in faunal assemblages. Brown and Davis (1995) discussed changes they noted in faunal distribution patterns of the Madrean Archipelago over 100 years. They mentioned the primary plant community affinities of each species, but not all changes have been due to changes in plant communities. Non-native fauna have also played an important role.

Non-native Species

A major threat to biological diversity is the intentional or accidental introduction of non-native species to ecosystems (Primack 1993). Such introductions can disrupt the ecological processes in their new communities through a number of mechanisms to include spread of disease, competition with native species, predation on native species, interference with reproductive performance of native species, and induced habitat change. Because the non-native species did not evolve in the ecosystem to which they were introduced, the results of translocations are unpredictable at best. In most cases, the introduced species is so poorly adapted to the new environs that it is unable to establish a sustained population and becomes extirpated, and impacts on the ecosystem are negligible. However, in some instances, non-native species thrive in their new environments and cause many ecological changes.

Within Mount Graham red squirrel habitat, non-native invertebrates are not well known. The introduced spruce aphid (*Elatobium abietinum*) has helped contribute to the stand-replacing insect outbreak in the spruce-fir forests by causing mortality directly and by weakening Engelmann spruce, which in turn may be killed by spruce beetles (*Dendroctonus rufipennis*). Of the four non-native vertebrates within red squirrel habitat, the Abert's squirrel poses the greatest threat to the Mount Graham red squirrel. The Abert's squirrel is discussed more fully in the Threats Assessment section.

Critical Habitat

On January 5, 1990, approximately 769 ha (1,900 ac) in 3 separate units were designated as Mount Graham Red Squirrel Critical Habitat (Figure 1, p. 8) (55 FR 425-429) (USFWS 1990). Critical habitat includes three areas:

1) the area above 3,048 m (10,000 ft) in elevation surrounding Hawk and Plain View peaks and a portion of the area above 2,987 m (9,800 ft);
2) the north-facing slopes of Heliograph Peak above 2,804 m (9,200 ft); and
3) the east-facing slope of Webb Peak above 2,957 m (9,700 ft).

The Mount Graham Red Squirrel Refugium established by the AICA has the same boundary as the designated critical habitat boundary surrounding Hawk and Plain View peaks (about 688 ha [1,700 acres]), but does not include critical habitat on Heliograph or Webb Peaks. The main attribute of these areas at that time was the existing dense stands of mature (about 300 years old) spruce-fir forest. Unfortunately, due to damage by insects, wildfire, and associated fire suppression activities, only approximately 112 ha (277 ac) of designated critical habitat currently provide potential habitat for the red squirrel (Hatten, unpub. data).

Human Use of the Pinaleño Mountains

Archaeological evidence for human use and occupation of the Pinaleño Mountains extends back thousands of years (Spoerl 2009). Fundamental precepts of Apache religion hold that the mountain is sacred to the tribe, providing a: 1) home to the mountain spirits, 2) source of natural resources and traditional medicine for ceremonial uses, 3) place of prayer, and 4) source of supernatural power (Welch 1997, Spoerl 2009). Mount Graham's historical association with Apache traditional cultural practices can be documented from at least the 1850s to the present (Spoerl 2009), and probably back to the early 1600s and possibly 1500s (Gillespie 2000, as cited in Spoerl 2009), although some Apache stories include ties to Mount Graham since time immemorial (Spoerl 2009).

In the early 1880s, settlers and their families came to the Gila Valley area in large numbers, and found respite from the heat of the valleys in the uplands of the Pinaleño Mountains (Sanderson and Koprowsi 2009). By the 1890s, settlers had built log cabins near the Mount Graham Sawmill at a place they called Columbine (Kellogg 1902). Columbine is still in use today, with special use permits for 14 cabins, covering about 10.1 ha (25 acres) (L. Engle, USFS, pers. comm. 2002).

On the eastern edge of the mountain, the USFS made lots available for lease at Turkey Flat, an area at the western edge of Jacobson Canyon, beginning in 1929 (Wilson 1995). By the late 1930s, the area consisted of 60 homes, a store, a lodge, tennis courts, and a public campground. Today, although the campground, lodge, store, and tennis courts are gone, Turkey Flat summer homes number 74 and occupy about 21 ha (52 ac) in the pine-mixed conifer transition zone, of which approximately 1.2 ha (3.0 ac) are within Mount Graham red squirrel habitat (Hatten 2009, USFS unpubl. data).

Recreation and logging were the impetus for continuing the Swift Trail to the top of the mountain. Finished to Columbine in the 1930s, a USFS road continued to Riggs Flat by the 1950s, which is now a 4.5 ha (11 ac) lake surrounded by a 117 ha (290 ac) campground. In all, 8 developed campgrounds encompass approximately 316 ha (781 ac) of Mount Graham red squirrel habitat (G. Froehlich, USFS, pers. comm. 2003).

USFS Administrative Sites are established at Heliograph Peak, Columbine Work Center, and Webb Peak Lookout. These sites occupy about 26 ha (64 ac) of Mount Graham red squirrel habitat. This is considerably less than what was occupied in the mid-1900s, due to gradual lessening of the work force required to remain on the mountain throughout the summer season. In the 1930s through the 1950s, fire lookout towers were established and in service on Clark, West, Webb, and Heliograph peaks (G. Froehlich, USFS, pers. comm. 2003).

The first road likely built into the Pinaleños traveled up Grant Creek to Moonshine Creek and crossed overland to Hospital Flat. Many current trails were originally roadways into canyons with sawmills. Many unpaved roads were closed to the public after 1988, when Congress passed the Arizona-Idaho Conservation Act. Some, such as FR 507, were closed and ripped to allow restoration of the forest. The upper reaches of FR 507 and FR 669 were obliterated and reforested in the early 1990s in accordance with the 1988 biological opinion for the Mount Graham International Observatory reasonable and prudent alternative 3 (USFWS 1988). The roads remained closed and unused until the 2004 Nuttall complex wildfire, when the roads were re-opened to facilitate fire suppression efforts. Since 2004, the roads have been gated to preclude public vehicular access, but have been used occasionally by the Forest Service to facilitate the restoration of burned areas that have not already regenerated with aspen. Tree planting and other restoration efforts have continued in the burned areas since 2007 (USFWS 2007a). In accordance with the Biological Opinion for the Nuttall Complex Wildfire, the roads are closed (gated) and are being allowed to revegetate naturally (USFWS 2007b).

Other developments in the Pinaleño Mountains include a Bible Camp of about 36 ha (89 acres), a Boy Scout Camp of about 4 ha (10 ac), and more recently, telescopes at the Mount Graham International Observatory (MGIO) at about 3.2 ha (8 ac), including roads. Telescopes may eventually cover up to 9.7 ha (24 ac) of a 60.7 ha (150 ac) research area (Arizona-Idaho Conservation Act 1988) (G. Froehlich, USFS, pers. comm. 2003). All areas of development within Mount Graham red squirrel habitat are summarized in Table 3. Because the maximum potential extent of area was used for each development, including future construction of telescopes in the MGIO complex (as allowed in the Arizona-Idaho Conservation Act), figures in

Table 3 should be considered the maximum extent of habitat permanently altered via development.

Table 3. Types of development with maximum size[1] within Mount Graham red squirrel habitat and potential habitat, as defined by Hatten (2009), in the Pinaleño Mountains, Coronado National Forest, Graham County, Arizona (G. Froehlich, USFS, pers. comm. 2003, Hatten 2009, USFWS unpublished data).

Development	Hectares	Acres	Percent of Habitat[2]
Bible Camp	36	89	0.5
Clark Peak Corrals	0.4	1	0.0
Columbine Admin Site	19	47	0.2
Columbine Corrals	2	5	0.0
Columbine Summer Homes	10	25	0.1
Cunningham	16	40	0.2
Heliograph Peak Electronic Site	6	15	0.1
Hospital Flat-Treasure Park	119	294	1.5
Mount Graham International Observatory	10	24	0.1
Prison Camp	0.8	2	0.0
Riggs Lake Campground	117	290	1.5
Shannon	8	20	0.1
Snow Flat	28	68	0.4
Soldier Creek	16	40	0.2
Turkey Flat Summer homes	1	3	0.0
Twilight Campground	11	28	0.1
Webb Peak Lookout	0.8	2	0.0
Roads	71.7	177	0.9
Total	**472.7**	**1170**	**5.9**

[1]Maximum size indicates entire land encumberance for each development, representing the maximum potential extent of each. Note that many of these areas currently still provide habitat for the Mount Graham red squirrel.
[2]Total area of potential Mount Graham red squirrel habitat = approximately 8,000 ha (19,768 ac).

Threats Assessment

Listing Factor A: Present Or Threatened Destruction, Modification, Or Curtailment Of Its Habitat Or Range

Catastrophic Wildfire

Catastrophic wildfire currently poses the greatest threat to the Mount Graham red squirrel through habitat loss and direct impacts to red squirrels within the fire boundary. Past practices of fire suppression, livestock grazing, and logging have resulted in a shift in the fire regime from short-interval, low-intensity fires to infrequent but larger, high-intensity fires (USFS 2000a). Fire size is currently limited by wildfire-suppression activities and fuel-reduction projects. Forest community composition has changed; Engelmann spruce and corkbark fir, both fire-intolerant species, now grow in much greater density and probably at lower elevations than in the past. This change is evidenced by the number of these trees less than 110 years old now growing in areas where the dominant, older trees are almost exclusively fire-resistent Douglas-fir, ponderosa pine, and southwestern white pine. In addition to accumulating fire-intolerant species, the mixed conifer forest has become dense with continuous horizontal (canopy cover) and vertical (ladder) fuels, meaning these forests no longer provide a fire buffer to the spruce-fir forest. The increased horizontal and vertical fuel load escalates fire intensity (hotter fires) and increases risk of crown fire (severity), both of which are more likely to alter and destroy key habitat features for the Mount Graham red squirrel. Research also indicates that fire can significantly reduce survivorship of individual squirrels with middens inside the fire boundary (Koprowski *et al*. 2006).

Insects and Pathogens

Engelmann spruce and corkbark fir populations in the Pinaleño Mountains that previously provided Mount Graham red squirrel habitat were severely depleted by recent catastrophic outbreaks of spruce beetle (*Nepytia janetae*), western balsam bark beetle (*Dryocoetes confusus*) (USFS 1999, 2000b), and spruce aphid (*Elatobium abietinum*) (Lynch 2004). The risk of similar catastrophic bark beetle outbreaks in the near term is low, although individual large trees will continue to be attacked if damaged by other agents. Spruce aphid is an exotic insect that specializes on Engelmann spruce and is likely to persist in this ecosystem with fairly frequent outbreaks (Lynch 2004). Repeated damage from spruce aphid defoliation may cause a shift in tree species away from Engelmann spruce in the future, as this spruce species continues to decrease, although the rate of loss is unknown. Additionally, armillaria root disease (a native, parasitic fungus), and associated blowdown, was observed in Engelmann spruce and corkbark fir in the mixed-conifer forest type in 2008. Armillaria root disease activity may be increasing due to the increase in food substrate that has become available from spruce and fir mortality. It appears that armillaria is infecting Engelmann spruce and other species weakened by drought and defoliators, and may be spreading to relatively healthy trees, although further study is warranted (A. Lynch and M.L. Fairweather, USFS, pers. comm. 2008). As the spruce-fir forest is lost due to insects, disease, and other sources of mortality, it is unclear what forest type may replace it (especially considering the effects of climate change as described below), and whether or not this forest type will continue to provide habitat for the Mount Graham red squirrel.

In the mixed conifer forest there are currently several possible insect threats to Mount Graham red squirrel habitat. These include bark beetles in Douglas-fir and southwestern white pine, and defoliators in Douglas-fir and spruce. These agents are generally not exclusive but interact with each other and other stressors, such as drought, root disease, and dwarf mistletoes, to cause tree mortality. While the mixed conifer forest has experienced outbreaks of most of these insects and pathogens previously, the reduction of Mount Graham red squirrel habitat within this forest type threatens the red squirrel population when combined with the loss of spruce-fir forest as described above. Increasing levels of drought due to climate change (see below) likely will work in combination with increasing levels of insect outbreaks and wildfires, which could directly impact the red squirrel's already limited habitat and food resources and decrease our ability to recover this subspecies.

Non-native Ungulates

Rocky Mountain elk is a non-native (Davis 1982, Truett 1996) ungulate in the Pinaleño Mountains that has severely impacted the growth of tree seedlings and saplings (Martin 2007, Fairweather *et al*. 2008) in other parts of Arizona where elk populations are high. Tree species most impacted by elk browse include aspen, Douglas-fir, white fir, and subalpine fir; elk even have been documented eating the succulent young buds of Engelmann spruce. Elk impacts are so severe in hardwood species, particularly aspen, that mortality of young shoots is common. Repeated browsing of young conifers by elk results in bushy elongated shrubs with limited height growth until a shoot reaches above browse height, which in some localized areas with high elk populations is a rare event. Over the past decade, elk populations have grown in the Pinaleños Mountains and have the potential to negatively affect red squirrel habitat if the population continues to increase.

Climate Change

Currently, Arizona is experiencing a severe, multiple-year drought (refer to http://www.azwater.gov/azdwr/StatewidePlanning/Drought/DroughtStatus.htm and http://www.climas.arizona.edu/outlooks/swco), and current models suggest that a 10 to 20 year (or longer) drought is anticipated (Swetnam and Betancourt 1998, Woodhouse and Overpeck 1998, McCabe *et al.* 2004, Seager *et al*. 2007). While this drought is apparently within natural historical variation (Swetnam and Betancourt 1998), mean annual temperatures are forecasted to rise 8.1-11.0^0 F in the 21st century (Intergovernmental Panel on Climate Change 2007), which in turn are predicted to be accompanied by a more arid climate (Seager *et al.* 2007), increasing insect outbreaks in Southwestern forests, and increasing wildfires (Betancourt 2004). Increasing levels of drought, insect outbreaks, and wildfires will likely directly impact the red squirrel's already limited habitat and food resources, decreasing our ability to recover this subspecies. For a full discussion on the impacts of climate change, see Listing Factor E.

Human Development

Human development, including road improvements to Swift Trail and the potential construction of up to four more telescopes in the future, is considered a threat to Mount Graham red squirrel habitat because it includes the direct effect of removal of vegetation (up to 5.9 percent of red squirrel habitat [Table 3]). This could result in decreased food sources, potential increase of tree blow-down, changes in microhabitat, and increased vulnerability to predation. Additional effects include increased habitat fragmentation, population isolation, and increased tourism. Increases in tourism and development can lead to noise disturbance and increased traffic.

Interaction among Threats

It is important to recognize the uncertainty of insect and pathogen response to changing forest conditions and, especially, climate. Under a warming climate regime with longer frost-free periods, insect outbreaks may be more damaging than in the past, with altered population dynamics of species we know to cause damage, as well as of species thought to be innocuous, such as the native spruce beetle, *N. janetae*. Wildfires will likely increase as temperatures increase and humidity decreases, and increased tourism to the area can lead to an increase in human-caused fires, as well. New species will invade the ecosystem, both exotic, such as the spruce aphid, and native species that expand their range. These insect and disease outbreaks threaten Mount Graham red squirrel habitat because they can physiologically stress trees, causing reduced cone crops and mortality, and altering forest structure. Additionally, as insects and diseases continue to compromise the health of some tree species (e.g. the spruce aphid influences the health of advanced spruce regeneration), regenerating forests may experience a shift toward other species (e.g. fir regeneration is not affected by the spruce aphid, and therefore may dominate spruce over time) (A. Lynch, USFS, pers. comm. 2003). Ultimately, this may negatively influence the food resources available to the red squirrel, as cone crop diversity changes or decreases.

Listing Factor B: Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

There has never been a commercial industry based on the capture or killing of the Mount Graham red squirrel. Occasional take prior to 1986 was known (USFS 1988); however, by 1986 several statutes including A.R.S. sections 17-303 and 17-304 and Commission Rules R12-4-301, R12-4- 801, R12-4-802, and R12-4-803 effectively prohibited recreational hunting of the Mount Graham red squirrel. After listing in 1987, take of Mount Graham red squirrels became a prohibited activity under the Endangered Species Act. Although several entities including AGFD, USFS, USFWS, and the UA engage in surveys of and research associated with the squirrel, all efforts are nonlethal. Furthermore, all research is strictly regulated pursuant to section 10 of the Endangered Species Act, and any injuries or mortalities associated with the activities are reported.

Exotic Abert's squirrels are hunted outside of the Mount Graham Red Squirrel Refugium, and illegal incidental take of red squirrels due to misidentification may occur but has not been reported.

Listing Factor C: Disease or Predation

Some authors have considered predation to have a negligible impact on red squirrel populations (Layne 1954, Stuart-Smith and Boutin 1995b), but others have suggested that a minimum of 19 percent and perhaps as much as 70 percent of red squirrel mortality was due to predators (Kemp and Keith 1970, Rusch and Reeder 1978, Wirsing *et al.* 2002). In a radiotelemetric study, 4 of 10 Mount Graham red squirrels were killed by avian predators (Kreighbaum and Van Pelt 1996). From June 2002 until July 2004, avian predators accounted for >60 percent and mammalian predators >13 percent of 30 mortalities on radiocollared adult Mount Graham red squirrels (J. Koprowski, UA, unpubl. data). Historical levels of predation are unknown in the Pinaleño Mountains, making inference difficult; however, mortality due to predation appears to be at the high extreme of those reported for other populations of red squirrels (Layne 1954, Kemp and Keith 1970, Rusch and Reeder 1978, Stuart-Smith and Boutin 1995b, Wirsing *et al.* 2002).

Several infectious agents have been reported for red squirrels including tularemia (Burroughs *et al.* 1945), *Haplosporangium* (Dowding 1947), adiaspiromycosis (Dvorak *et al.* 1965), Silverwater virus (Hoff *et al.* 1971), California encephalitis (Masterson *et al.* 1971), and Powassan virus (McLean 1963, McLean *et al.* 1968). A diversity of parasites has been reported from red squirrels in various parts of their range (reviewed by Flyger and Gates 1982). However, parasite and disease infestations are not known to significantly contribute to the mortality of Mount Graham red squirrels (J. Koprowski, UA, pers. comm. 2008).

Listing Factor D: Inadequacy of Existing Regulatory Mechanisms

Protections afforded by the Endangered Species Act reduce direct take of the squirrel and loss of habitat due to human activities, but do little if anything to prevent loss of mature trees due to insect infestation or wildfire. Because the squirrel exists exclusively on Coronado National Forest lands, almost all actions within the squirrel's habitat must undergo review by the USFWS pursuant to section 7 of the Endangered Species Act. Section 7 prohibits jeopardizing the continued existence of a species by a Federal agency. However, although section 7 consultations tend to reduce project effects to the squirrel and its habitat, the Mount Graham red squirrel would likely benefit from more section 7 actions geared toward enhancing recovery. Without a focus on combining section 7 actions with actions recommended in the recovery plan, the status of the species could continue to decline despite consultations.

The Coronado National Forest, under CFR Title 36, Chapter 2, has the authority to impose restrictions on fire use and live tree cutting within its boundaries. This authority may reduce sources of ignition (e.g., restrictions on fire and recreational access) during critically dry periods, and provide some level of protection from habitat alteration (e.g., restrictions on fuel wood cutting). The Forest also regulates the location and types of recreational uses and access occurring on its land, livestock grazing, mining, and a variety of other human activities that can affect the squirrel and its habitat. Several Arizona statutes and Arizona Game and Fish Commission rules effectively prohibit recreational hunting of the Mount Graham red squirrel (see discussion under Listing Factor B). However, these hunting statutes and rules do not address issues regarding the red squirrel's habitat.

The greatest overarching threat to the Mount Graham red squirrel is the loss or potential loss of its habitat. Existing regulatory mechanisms have helped to reduce habitat loss and decline in numbers of the red squirrel, but they are inadequate to affect recovery of the species.

Listing Factor E: Other Natural or Manmade Factors Affecting Its Continued Existence

<u>Human-caused Mortality</u>
Mortality of red squirrels due to collision with motor vehicles has long been noted (Hatt 1929). Vehicular traffic on the Swift Trail (due to recreation and human development) is primarily limited to 25 miles per hour on the stretch of road that passes through typical red squirrel habitat. The road is full of tight, winding curves and switchbacks; lower speed limits are for safety to people, also. Much road traffic occurs on the Swift Trail, day and night. The Forest Service, University of Arizona, Steward Observatory contractors, workers, and employees, and other people who travel the Swift Trail on an almost-daily basis have been instructed to collect (if possible), identify, and notify the USFS or the USFWS of any and all road-killed squirrels. Appropriate personnel identify the species, and red squirrel mortalities are immediately reported to the USFWS office in Tucson, Arizona. Since the Mount Graham red squirrel was listed as endangered in 1987, a total of eight road-killed squirrels has been reported, with two being the most reported in any one year (both 1989 and 2004). However, the total number of red squirrels killed on the road is likely greater due to irregular monitoring and the rapidity at which dead animals are removed from the road by scavengers. If remains of the specimens are in good enough condition, they can be sent to Dr. John Koprowski, University of Arizona, School of Natural Resources.

<u>Small Population Size</u>
Small, narrowly distributed populations, such as that of Mount Graham red squirrel, are vulnerable to extinction (Soulé 1987, Belovsky *et al.* 1989). As populations decrease in size, their vulnerability to environmental changes increases, including slow, long-term trends

(deterministic) and brief, high-intensity (stochastic) events. These environmental changes can influence demographics of a population directly, through changes in survival and recruitment rates, and indirectly, through changes in characteristics of the physical environment that affect the quantity and quality of habitat. Given the unprecedented reductions in habitat area and quality due to factors such as wildfire, fire suppression, insect damage, development, and forest succession, the likelihood of reductions in population size and connectivity among habitat patches has increased concerns about persistence of this squirrel population.

Demographic stochasticity is the random change in characteristics of populations including sex ratio, fecundity (the capacity to produce offspring), and mortality, and is thought to have an important influence on extinction risk (Goodman 1987, Gabriel and Bürger 1992, Lande 1993). Population Viability Analyses specific to the Mount Graham red squirrel suggest the population may be sensitive to all demographic factors, especially adult mortality (Beunau and Gerber 2004, Rushton *et al*. 2006). Because red squirrels are only in estrus for less than one day per breeding season, and instances of females producing a second litter during a year are rare (Lair 1985, Steele 1998), Allee effects could become increasingly consequential for Mount Graham red squirrels at low densities.

Dispersal patterns can influence population persistence (Clobert *et al*. 2001), and dispersal patterns may be influenced by human developments and activities within red squirrel habitat. Mammals typically have low levels of natal (pertaining to birth) philopatry (the tendency of an individual to remain in the same location) and high levels of natal dispersal (Greenwood 1980, Waser and Jones 1983, Johnson and Gaines 1990), which is true of most tree squirrels, including red squirrels (Koprowski 1998). Red squirrels are capable of dispersing distances of >2 km (1.2 mi) (Larsen and Boutin 1994, Steele 1998, Goheen *et al.* 2003) and juveniles have dispersed similar distances on Mount Graham (Kreighbaum and Van Pelt 1996; Rushton *et al*. 2006; J. Koprowski, UA, pers. obs.). Maintaining healthy forests as well as a high degree of connectivity among forested patches in the Pinaleño Mountains appears to be an appropriate strategy for facilitating movements of dispersing individuals, and minimizing environmental and demographic effects to which small populations are vulnerable.

<u>Genetics</u>

The likelihood of genetic problems emerging in populations also increases as population size decreases (Lande 1988, 1994; Mills and Smouse 1994, Lande 1995, Frankham 1995a, 1995b, 1995c). Most adverse genetic consequences stem from reductions in available genetic variation caused by declines in population size. Populations typically have lower genetic variation after undergoing large reductions in population size, known as population bottlenecks (Maruyama and Kimura 1980, Hedrick 1995, 1996; Conner and White 1999). Smaller populations also have a higher probability of genetic drift**,** which is the result of changes in allele frequencies due to random chance. If population numbers remain low, the probability of matings between individuals with a high degree of genetic similarity increases, which can reduce rates of survival and fecundity (Hedrick 1985, Lande 1988). Adverse consequences of matings between closely related individuals are known as inbreeding depression, which is a result of increased genetic homozygosity (a condition in which two members of a pair of genes are alike) that results in the expression of deleterious recessive alleles (harmful genetic traits) or decreased heterozygosity (a condition in which two members of a gene pair differ) where heterozygote advantage is present

(Crow 1948). The ability of a population to express a suitable phenotype (the external, physical makeup of an individual as opposed to the genetic constitution or genotype) in response to future environmental changes depends in part on the genetic diversity inherent in that population, as measured by the number of alleles (Bürger and Lynch 1995, Edwards and Potts 1996). Phenotypic variation in life-history traits that has a genetic basis, such as timing of reproduction, age at first reproduction, offspring size, and litter size, can increase population persistence (Conner and White 1999, Allendorf and Ryman 2002). Therefore, loss of genetic variation brings an associated lost potential for a population to respond to environmental changes through a shift in genotypic frequency, which has been called loss of evolutionary potential (Allendorf and Ryman 2002).

Recent work by Fitak and Culver (2009) suggests that while Mount Graham red squirrels appear to be randomly mating with each other, on average any 2 individuals are 90 percent related to each other. Mount Graham red squirrels exhibit extremely reduced measures of genetic variability and appear to have experienced a recent genetic bottleneck. The work of Fitak and Cluver (2009) indicates that Mount Graham red squirrels have been isolated long enough to have accumulated mutations not present in other populations, as well as mutations within their own population.

Abert's Squirrels

Another threat to the Mount Graham red squirrel is that posed by the introduced Abert's squirrel. The Abert's squirrel is the principal non-native vertebrate species of potential indirect and direct importance to the Mount Graham red squirrel because it inhabits a similar niche in both low and high-elevation forests. Both Abert's and Mount Graham red squirrels are members of the squirrel family, Sciuridae, subfamily Sciurinae, tribe Sciurini, with a divergence time estimated as prior to the Pleistocene and likely some three million years before present (Hafner 1984). Abert's squirrels are native to the northern Sierra Madre Occidental of Mexico and parts of Arizona, Colorado, New Mexico, Utah, and Wyoming (Nash and Seaman 1977). Although Abert's squirrels are often sympatric with red squirrels in the United States and are naturally found to the north in the White Mountains of east-central Arizona and to the south in the northern Sierra Madre Occidental, no evidence currently exists to suggest that Abert's squirrels coexisted with red squirrels naturally in the Pinaleño Mountains in recent geologic times (approximately 10,000 years before present).

Forty-nine Abert's squirrels were trapped in October 1941 and 20 in May 1943 at Fort Valley north of Flagstaff and released in the Pinaleño Mountains by the Arizona Game and Fish Department; this is likely the origin of the Abert's squirrel population in the Pinaleños (Hoffmeister 1956). Abert's squirrels occur throughout the highest elevations in the Pinaleño Mountains, including the spruce-fir forests (Hoffmeister 1956, 1986; Hutton *et al.* 2003), but also use use Gambel oaks in riparian areas low on Mount Graham (Brown 1986). Since the loss of most of the spruce-fir forest on the mountain, Abert's and Mount Graham red squirrels are in closer association and likely compete more for resources (Rushton *et al*. 2006).

Abert's squirrels likely impact Mount Graham red squirrels through competition for food resources (Hutton *et al.* 2003, Edelman 2004, Edelman and Koprowski 2005), nest sites (Edelman and Koprowski 2006), and dispersal territory (Steele and Koprowski 2001), and potentially can increase predator density by providing an additional food source, leading to higher predation rates for red squirrels. Conversely, Abert's squirrels could decrease per capita predation on red squirrels by serving as an additional food source for predators. Rushton *et al*. (2006) determined competition with Abert's squirrels has the potential for a much greater impact on Mount Graham red squirrel population size when compared to plausible increases in predation, and suggested further research into and monitoring of the effects of competition and predation on red squirrels.

Climate Change

Strong evidence exists that global climates are changing in response to increasing emissions of greenhouse gases (IPCC 2007), and that changing climates are affecting forest ecosystems throughout the world either directly or indirectly through altered disturbance regimes (e.g., Ayres and Lombardero 2000, Breshears *et al*. 2005, 2009, Bonan 2008, Raffa *et al*. 2008, van Mantgem *et al*. 2009, Negron *et al*. 2009, Allen *et al*. 2010). Understanding the effects of climate change on forests is critical to informing current forest management and conservation planning for the future (Allen *et al*. 2010). This includes recovery planning for the Mount Graham red squirrel, which inhabits high-elevation forests only in the Pinaleño Mountains.

Models of projected climate change typically focus on two variables: temperature and precipitation. In general, model predictions appear to be more robust with respect to temperature than precipitation (Sheppard *et al*. 2002). How climate change will affect summer monsoonal precipitation in the southwestern U.S. is even less certain, because precipitation predictions are based on continental-scale general circulation models (GCMs) that do not yet account for regional phenomena such as those that control monsoonal rainfall (Weiss and Overpeck 2005, Archer and Predick 2008).

The southwestern U.S. exhibits high climatic complexity and variability in general. This is due to both complex topography and proximity to the Pacific Ocean, the Gulf of California, and the Gulf of Mexico (Brown and Comrie 2002, Sheppard *et al*. 2002). Because of this complexity and steep environmental gradients, many ecosystems within the southwestern U.S. may be particularly vulnerable to climate change (Archer and Predick 2008). For example, the recent temperature increase in the southwest is among the most rapid in the nation, and is significantly greater than the global average in some areas (Guido *et al*. 2009). Predicted climate change impacts in the southwest include warmer temperatures, fewer frost days, greater water demand by plants, and an increased frequency of extreme weather events such as heat waves, droughts, and floods (Weiss and Overpeck 2005, Archer and Predick 2008). Further, warmer nights and projected declines in snow pack, coupled with earlier spring snow melt, will reduce water supply, lengthen the dry season, create conditions for drought and insect outbreaks, and increase the frequency and intensity of wildfires as well as the duration of the wildfire season (Allen *et al*. 2010). Areas within the southwest, including Arizona, are currently experiencing a severe, multiple-year drought, and current models suggest that a 10 to 20 year (or longer) drought is anticipated (Swetnam and Betancourt 1998, Woodhouse and Overpeck 1998, McCabe *et al*. 2004, Seager *et al*. 2007). Prolonged drought, combined with warmer temperatures, may most likely cause increases in insect outbreaks and increased wildfires in southwestern forests (Betancourt 2004, Allen *et al*. 2010). Severe or prolonged drought may cause mature trees to be more susceptible to insects and disease (Hanson and Weltzin 2000, Mueller *et al*. 2005, van Mantgem *et al*. 2009, see also Negron *et al*. 2009: Figure 3).

The effects of climate change on rare, endangered, and endemic species are highly variable (U.S. Environmental Protectin Agency 2009), and will differ depending upon life history characteristics (Travis 2003) and dispersal abilities. Climate change has already resulted in significant effects on species and ecosystems (Gitay *et al*. 2002, Hannah and Lovejoy 2003, Root *et al*. 2003, Harris *et al*. 2006, Parmesan 2006). Range-restricted species, such as polar and mountaintop species, are particularly susceptible to the effects of climate change, showing severe range contractions and extinctions due to recent changes in climate (Parmesan 2006). The ranges of high-elevation, small-mammal species in Yosemite National Park have contracted over the past century, while formerly low-elevation species expanded theirs (Moritz *et al*. 2008). In the northern Great Lakes region, small mammal assemblages have shifted from domination by northern species to domination by southern species (Myers *et al*. 2009). Additionally, uphill shifts in butterfly species richness and composition, as well as forest plant species, have been observed in Spain and Western Europe (Wilson *et al*. 2007, Lenoir *et al*. 2008, respectively). Studies such as these indicate a specialized mountane species, like the Mount Graham red squirrel, may be particularly vulnerable to the effects of climate change.

The U.S. Environmental Protection Agency has developed a framework for categorizing the relative vulnerability of threatened and endangered species to climate change (U.S. Environmental Protection Agency 2009). Using this framework, we categorized the baseline vulnerability of the Mount Graham red squirrel to extinction by analyzing elements of the subspecies' life history, demographics, and conservation status, and then combined this with their potential physiological, behavioral, demographic, and ecological response to climate change. The results of this assessment indicate that there is a high level of certainty that the Mount Graham red squirrel is critically vulnerable to the impacts of climate change (Appendix D). The greatest impact of climate change on the Mount Graham red squirrel is likely to occur through a direct loss of habitat. As discussed under Listing Factor A, a warming climate regime may lead to increasing levels of insect and disease outbreaks, wildfires, and drought. Using tree ring data, Swetnam and Lynch (1993) and Ryerson *et al*. (2003) examined the correlation between western spruce bud worm outbreaks and climate variability over multi-century periods. They found that periods of increased and decreased budworm activity coincided with wetter and drier periods, respectively. Allen *et al*. (2010) and Breshears *et al*. (2009) documented recent examples of drought- and heat-related forest stress and dieback (defined as tree mortality noticeably above usual mortality levels) from all forested continents. Drought-related mortality occurred in forest types with tree species that included *Abies*, *Populus*, and *Pseudotsuga* species, which are all found within Mount Graham red squirrel habitat. Increasing levels of drought, along with associated insect outbreaks and wildfires, could rapidly and dramatically affect Mount Graham red squirrel habitat by altering the forest structure and available food resources within the Pinaleño Mountains.

Threats Assessment Summary

When the Mount Graham red squirrel was listed in 1987, its population was estimated at 280 individuals. The threats to the species were determined to be its small population size and range;

changes in forest age structure and density within the squirrel's habitat; loss of habitat due to development, road construction, and forest fire; and competition with the introduced Abert's squirrel. In 2009, the number of red squirrels was estimated near 260 individuals, with the population having climbed to over 560 individuals in the late 1990s, and falling to near 200 individuals in 2006 (Table 2, Figure 2). The swing in population size seems to correlate mostly with food resources (Koprowski *et al*. 2005). The threats to the red squirrel's habitat that were identified at the time of listing continue today, compounded by the additional threats of climate change (including drought), insect and parasite infestations, and fire suppression activities. Recent research also indicates that predation, competition with Abert's squirrels, and demographic factors (mainly due to its small population size) may impact the Mount Graham red squirrel population more than expected.

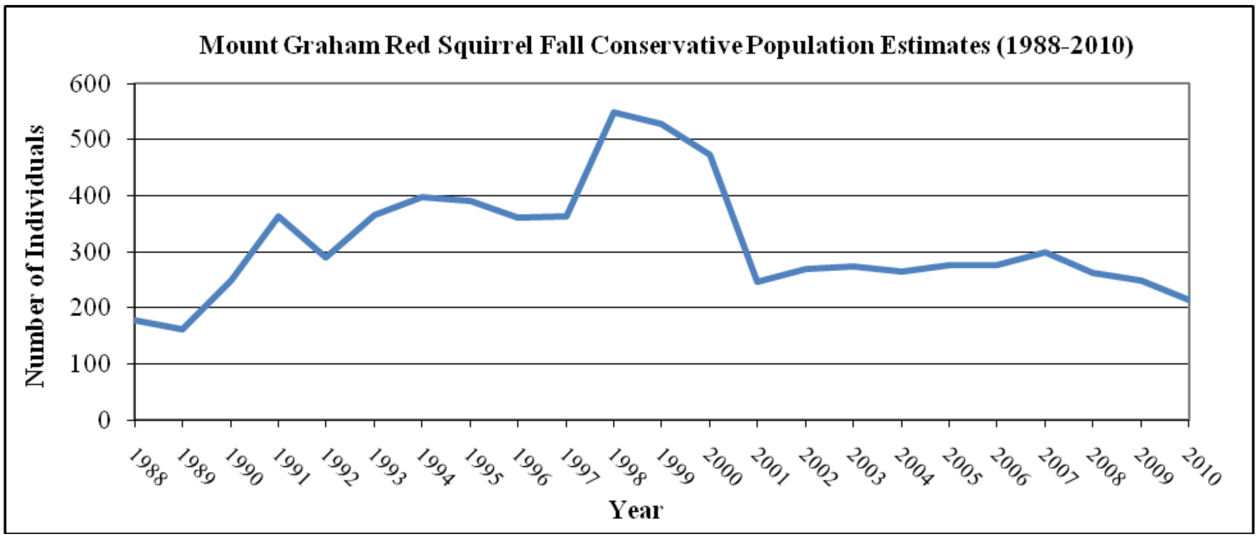

Figure 2. Conservative population estimates of autumn surveys from 1988 to 2010. See Appendix A for the methodology used to calculate these estimates.

Previous and Ongoing Conservation Measures

Coronado National Forest Management

Because the entire range of the Mount Graham red squirrel is within the Safford Ranger District of the Coronado National Forest, all ongoing and future conservation measures are either led by or coordinated with the USFS. The Mount Graham Red Squirrel Recovery Plan (USFWS 1993) established the basic recommendations for the USFS to manage habitat for the squirrel. Many of the recommendations in the recovery plan had already been adopted by the Coronado in its Forest and Land Resource Management Plan (Forest Plan) (USFS 1986, as amended; USFWS 2005). The Forest Plan, which is currently under revision, establishes Standards and Guidelines that determine how to manage the Coronado National Forest. The Forest Plan specifically addresses conservation needs for the Mount Graham red squirrel in Management Areas 2 and 2A, which essentially cover the range of the subspecies. The Standards and Guidelines were last updated in 2005 to address the needs of the Mount Graham red squirrel as recommended by the USFWS (USFS 1986, as amended; USFWS 2005).

Management Area 2 is primarily the mixed conifer zone and 2A is the subalpine zone, which includes the designated critical habitat (referred to in the Forest Plan as the "red squirrel refugium"). Management and public use of USFS lands is more restrictive in 2A. The emphasis on red squirrel conservation in the Forest Plan is clear. The Forest Plan states that "red squirrel habitat needs will supersede the needs of all other species". Management Area Standards and Guidelines include: (1) the closure and rehabilitation of roads; (2) trail and trailhead closures (2A only); (3) the decreased use of motorized vehicles; (4) public education; (5) research on Mount Graham red squirrel biology; (6) 10 years (or more) of monitoring; (7) use of silvicultural treatments to improve forest conditions, including thinning and prescribed burning, as well as creating wildlife openings; and (8) fuelwood harvest guidelines. All trails (and roads) in the Mount Graham Red Squirrel Refugium are currently closed to the public; however two small units of critical habitat, located outside of the refugium on Webb and Heliograph Peaks, are open to hiking.

Pinaleño Ecosystem Management Demonstration Project

The Pinaleño Ecosystem Management (PEM) demonstration project, implemented from 2000 through 2008, is a large project in the mixed conifer zone of the Pinaleños. The PEM project involved thinning, piling, burning, and sometimes broadcast burning in an area occupied by the Mount Graham red squirrel, northern goshawk, Mexican spotted owl, and numerous USFS Sensitive Species. The PEM design consists of a series of blocks with differing densities of Mount Graham red squirrel middens. High-density blocks were thinned (down logs <16 in and standing trees and snags <9 in dbh could be removed), and low-density blocks were similarly thinned and then broadcast burned. In all cases, squirrel middens were protected by a 15.24-m (50-ft) radius no-touch zone. Currently, the University of Arizona is conducting a radio-telemetry study of Mount Graham red squirrels in part of the PEM project area to determine how squirrels respond to short- and long-term effects of these fuel management treatments. They are also conducting radio-telemetry studies on natural history, habitat use, and demographics of Mount Graham red squirrels.

Pinaleño Ecosystem Restoration Project

Currently, the Coronado National Forest has also proposed a larger fuel reduction and forest restoration project called the Pinaleño Ecosystem Restoration Project (PERP). This project is designed to help reduce the threat of catastrophic wildfire in much of the remaining mixed conifer zone, and will begin to set the forest on a trajectory that will allow a low-intensity fire cycle. Large-diameter trees, snags, and logs of all canopy species will be retained, while select smaller-diameter under- and mid-story trees will be removed to achieve desired forest conditions (considering species composition, life form structure, and landscape matrix of age classes). The mixed conifer forest currently has the largest block of remaining squirrel habitat, and monitoring of impacts to the red squirrel and its habitat is incorporated into the project's design. This project is currently undergoing formal consultation, and will take a decade or more to complete. The success of this project in reducing the threat of stand-replacing wildfire, while having minimal short-term impact on the Mount Graham red squirrel, will be key to setting the stage for recovery of the species.

Biological Constraints and Needs

The Mount Graham red squirrel is primarily habitat limited. Investigations continue into its specific needs, but in general it requires old growth mixed conifer and spruce-fir forests above about 2,425 m (8,000 ft) with a dense closed canopy and numerous dead and down logs. An ample supply of closed conifer cones is also critical to the population. Recovery of the Mount Graham red squirrel will require long-term management of the Pinaleño Mountains to retain what remains of those vegetation communities and increase their areal extent in the future.

PART II. RECOVERY

The following sections present a strategy to recover the species, including objective and measurable recovery criteria to achieve downlisting and delisting, and site-specific management actions to monitor and reduce or remove threats to Mount Graham red squirrel, as required under section 4 of the ESA. The Recovery Plan also addresses the five statutory listing/recovery factors (section 4(a)(1) of the ESA) to demonstrate how the recovery criteria and actions will lead to removal of the squirrel from the lists of Threatened and Endangered Species.

Recovery Strategy

Recovery of the Mount Graham red squirrel will likely be long and challenging. Its limited habitat, isolation to one mountain range, and demographic characteristics (relatively low productivity and short lifespan) restrict its ability to rebound quickly from threats that impact both the squirrel and its habitat. Currently, threats to the red squirrel include habitat degradation and loss through catastrophic wildfire, fire suppression activities, insect outbreaks, climate change, and human development, as well as competition with Abert's squirrels and predation. Loss of habitat due to recent fires and insect damage has long term impacts; ameliorating those losses and restoring forest habitat and squirrel populations will take many decades, if not centuries. The recovery strategy has five key elements designed to conserve the red squirrel throughout its historical range:

1) protect and manage the remaining population and habitat;
2) restore and create habitat to allow for the existence of a viable and robust population, including a subpopulation on West Peak;
3) research the conservation biology of the Mount Graham red squirrel with the objective of facilitating efficient recovery;
4) develop support and build partnerships to facilitate recovery; and
5) monitor progress towards recovery and practice adaptive management, through which the recovery plan and management actions are revised to reflect new information developed through research and monitoring.

To ensure recovery, the Mount Graham red squirrel must reach a population level and have sufficient habitat available to provide for its long-term persistence in light of the numerous factors that threaten the species. A critical first step is to protect and manage the remaining population of the squirrel and its habitat. Management will include, but is not limited to, maintaining and improving the spruce-fir and mixed conifer biomes while balancing the need to reduce risk of catastrophic wildfire with the needs of the squirrel. A key component in protecting existing populations and habitat is the Pinaleño Ecosystem Restoration Project (PERP, currently undergoing formal consultation), which is a 2,329-hectare (5,754-acre) fuels reduction project designed by the USFS in coordination with others to be conducted over a 10-year period. Threats of insect outbreaks and catastrophic wildfire will be addressed by PERP within the project boundaries, with the recovery of the Mount Graham red squirrel as the overarching goal. This will be achieved by reducing wildfire risk in key locations, as well as boosting tree productivity and health (see Appendix B). When completed, this project can be used to evaluate different types of treatments in different areas, informing the need to treat other areas within the

Pinaleño Mountains, should that become necessary. Restoring forest health and reducing the threat of catastrophic wildfire and insect outbreaks are of paramount importance. Protection of the existing population and habitat will be achieved, in part, through USFS forest and land use management, facilitated by section 7 consultations and agreements with the USFS.

Because population numbers and habitat are currently much reduced, projects to restore and/or create red squirrel habitat must also be developed and implemented. The USFS is implementing a reforestation project planting corkbark/subalpine fire (*Abies lasiocarpa*) and Engelmann spruce (*Picea engalmannii*) seedlings in areas that experienced moderate- to high-severity burns during the Nuttall-Gibson Complex Fire in 2004. This planting project should begin the process and help us learn more about reestablishing red squirrel habitat in areas where it has been lost to insect damage or fire. Other actions to be explored could include closing unnecessary roads and re-seeding or actively planting them. Trails and roadways that are wider than necessary and bare-earth skid trails could be re-seeded or planted. Other bare-earth areas (not meadows) could be inspected for reforestation, and the impacts of human developments should continue to be evaluated. Forest-system roads should be examined as to how they affect the soils and landscape; erosion should be repaired quickly.

Additionally, anectdotal evidence suggests red squirrels may be present on West Peak. This should be investigated and the forest conditions between West Peak and the main population of squirrels should be assessed, as well. If appropriate, tree-planting projects should be considered between West Peak and the main population to create inviting corridor conditions for the squirrels and enhance the possibility of dispersal and genetic flow between these two areas.

Research will be conducted to promote conservation and management of the Mount Graham red squirrel. Specifically, information will be developed to improve this recovery strategy and the implementation of recovery actions. Critical areas of research include: (1) determining the husbandry needs of the squirrel (in case a captive population is deemed necessary); (2) reducing the effects of Abert's squirrels in key areas; (3) investigating effects of PERP treatments in stands adjacent to Midden Protection Areas – areas containing a high concentration of middens – on red squirrels (e.g., habitat effects, effects to food resources, predation, etc.); and (4) analyzing effects of stand treatments on fire behavior through modeling.

Many of the actions needed to recover the Mount Graham red squirrel will affect the human environment, as well as the squirrel and its habitat. Involving the public and stakeholders in the implementation of those actions is key to developing an understanding of why actions need to be taken and garnering support for the recovery program. Local or regional recovery implementation should focus on broadly inclusive, community-based planning. This has already begun in the Pinaleño Mountains with the initiation of the Pinaleño Partnership, involving Federal and state agencies, summer home owners, elected officials, and other interested parties. Education and outreach will complement these efforts by establishing support and understanding of the recovery program, including developing public information about Mount Graham red squirrel recovery at zoological institutions, as well as developing conservation partnerships with landowners and land managers, recreationists, ranchers, anglers, and others that use and enjoy public lands. Coordination and outreach through the Pinaleño Partnership and other avenues, such as Stakeholder and Technical subgroups of the red squirrel recovery team, will be pursued to inform the public of this recovery plan and to include public input into recovery implementation. Momentum for continued progress toward recovery will be facilitated by annual or more frequent meetings of Stakeholder and Technical subgroups. The Pinaleño Partnership is willing to assist in facilitating these meetings.

Monitoring will be conducted to track the status of the Mount Graham red squirrel population, to assess threats to the species and its habitat (e.g., increase in predation, increase in browsing by ungulates, etc.), and to evaluate the implementation and effectiveness of this recovery plan. A scientifically acceptable monitoring protocol will be developed, and monitoring data will be compiled into annual reports to assess recovery plan implementation and whether the recovery criteria have been met. Where appropriate, such data or summaries should be made available to the public as part of the outreach program. As data is gathered and analyzed through monitoring, research, and other sources, this recovery plan and its implementation will be revised based on new information to ensure that efficiency and effectiveness of the recovery effort are maximized.

Recovery Goal

Goal – The goal of this revised recovery plan is to assure the long-term viability of the Mount Graham red squirrel in the wild, allowing initially for reclassification to threatened status and, ultimately, for removal from the List of Endangered and Threatened Wildlife.

Recovery Objectives and Criteria

Objective 1 – Restore and maintain sufficient Mount Graham red squirrel habitat to ensure the species' survival despite environmental stochasticity and the threat of climate change.

Criterion 1A (downlisting) – A mosaic of at least 70 percent of the range, or 5,600 ha (13,838 ac), of the Mount Graham red squirrel meets the criteria for habitat listed in the justification below, and management agreements among the USFWS, Coronado National Forest, and AGFD that will protect this habitat indefinitely are in place and being implemented. (Listing Factors A and D)

Criterion 1B (delisting) – A mosaic of at least 80 percent of the range, or 6,400 ha (15,815 ac), of the Mount Graham red squirrel meets the criteria for habitat listed in the justification below, and management agreements among the USFWS, Coronado National Forest, and AGFD that will protect this habitat indefinitely are in place and being implemented. (Listing Factors A and D)

Objective 2 – Maintain a self-sustaining population of Mount Graham red squirrels sufficient to ensure the species' survival.

Criterion 2A (downlisting) – There is statistical confidence (90 percent) that the rate of increase over a time of 10 years (5 generations) is 20 percent or greater of the known population, as measured by mountain-wide monitoring. (Listing Factors C and E)

Criterion 2B (delisting) – Once downlisting criteria are achieved, there is statistical confidence (90 percent) that the rate of increase over the following 20 years (10 generations) is increasing or stable, as measured by mountain-wide monitoring. (Listing Factors C and E)

Justification: Criteria 1A and 1B (Listing Factors A and D)

Habitat loss is the major factor currently threatening the persistence of the Mount Graham red squirrel. The subspecies' habitat has been impacted by past human practices (such as fire suppression, logging, and grazing), wildfires, and insect and parasite damage. Unhealthy forest conditions still exist within the squirrel's remaining habitat, making it susceptible to more wildfire and insect and disease outbreaks. Maintaining, restoring, and creating Mount Graham red squirrel habitat is necessary to recover this species.

Based on a habitat assessment by Hatten (2009), a boundary encompassing approximately 8,000 ha (19,768 ac) surrounds all areas within which Mount Graham red squirrel habitat potentially could exist. Within this boundary, areas are considered habitat if they meet the following conditions:

1) They are within the mixed conifer, ecotone, and spruce-fir series AND
2) They are above 2,744 m (9,000 ft) OR
3) If they are below 2,744 m (9,000 ft), they meet the following criteria:
    a. > 2,353 m (7,720 ft) elevation
    b. north or east aspect
    c. < 45-degree slope

The mixed conifer, ecotone, and spruce-fir series are represented on Landsat Thematic Mapper satellite imagery by Normalized Difference Vegetation Index classes 8-12 and spectral classes 1-6. Elevation, aspect, and slope can be derived using a Digital Elevation Model. A complete description of the methods for determining whether areas meet the habitat conditions above can be found in Appendix C. As technology and techniques for determining red squirrel habitat advance and research continues on the habitat requirements of the red squirrel, the boundary and definition of habitat should be modified as appropriate.

Criterion 1A establishes a target of at least 70 percent of the range of the Mount Graham red squirrel, or 5,600 ha (13,838 ac) to meet thehabitat criteria for downlisting. This amount of habitat is slightly greater than what was available to the red squirrel at the time of its listing in 1987. At that time, which was prior to the insect outbreaks and Clark Peak and Nuttall Complex Fires, approximately 5,365 ha (13,257 ac) of habitat were in a condition suitable for squirrel occupancy (Hatten 2009). In addition to the amount of available habitat, this criterion also requires that management agreements among USFWS, Coronado National Forest, and AGFD are in place and being implemented that will protect this habitat indefinitely.

Criterion 1B establishes a target of at least 80 percent of the range of the Mount Graham red squirrel, or 6,400 ha (15,815 ac), to meet the habitat criteria to delist the squirrel. This amount of red squirrel habitat represents the best estimate, based on recommendations by the Technical Subgroup of the Recovery Team, and provides flexibility to manage this habitat as a mosaic of naturally occurring landscapes representing healthy forest conditions. This number can be revised as additional information becomes available, but the area should include habitat on West Peak, as well as dispersal corridors between West Peak and the current population. Healthy forest conditions will be indicated by tree stocking levels and fuel load conditions such that fire can be allowed to burn naturally across the landscape without risking the loss of all red squirrel habitat and jeopardizing the persistence of the squirrel. A forest silviculturist should be consulted during this process, and standard forest vegetation modeling programs, such as the Forest Vegetation Simulator, FlamMap, LANDFIRE, etc., may be used to model fire potential and risk of insect and pathogen outbreaks based on current forest conditions. Furthermore, long-term management actions will be in place that will minimize threats to this habitat. These management actions must address the threats of destruction, modification, and/or curtailment of the squirrel's habitat or range, including threats of catastrophic, stand-replacing wildfire, insect and disease damage, and habitat loss due to human developments.

Justification: Criteria 2A and 2B (Listing Factors C and E)

No historical (pre-listing) information exists on range-wide population levels of the Mount Graham red squirrel; therefore the Recovery Team does not feel that establishing population targets are appropriate as recovery criteria. Instead, the Team recommends an approach based on an observed positive population trend over a period of time sufficient to capture stochastic events and long-term patterns within the population. They recommend that criteria for downlisting and delisting be based on observation of a positive population trend over at least 10 years (5 generations) for downlisting, and over an additional 20 years (10 generations) for delisting, using mountain-wide monitoring information. These timeframes, in addition to reaching the habitat criteria, above, should provide evidence that the ecological processes required for maintaining the red squirrel population have been sufficiently restored to warrant consideration for downlisting and delisting.

Criteria 2A and 2B are based on monitoring data that are gathered over the range of the red squirrel during the fall (Appendix A). Natural variability in population size and inherent measurement error make it difficult to detect realistic, natural increases (i.e., less than two percent per year) in Mount Graham red squirrel populations in as few as 10 years. In particular, surveys conducted in the spring likely include significant measurement error because of the difficulty in detecting squirrels during this time of year due to their more dispersed foraging behavior. Fall surveys tend to provide more reliable data, as red squirrels are caching cones in their middens for the upcoming winter, and therefore midden occupancy is usually easier to detect. Monitoring data have been collected on Mount Graham since 1986; however, prior to 2001, the number of middens included in the final population estimate was likely unrealistically high because of the way "disappeared" middens were handled. For this reason, the Technical Team recommends beginning these calculations with the 2001 Fall survey estimates. Power analysis of these data indicates that a 2 percent annual increase in the population is detectable over a period of 10 years (alpha=0.05, beta=0.10), which coincides with 5 generations of red squirrels. The team felt this was an appropriate demographic target to warrant downlisting. To reach delisting, the population must continue to increase or stabilize over the next 20 year period, which is equivalent to 10 generations of red squirrels. A two-tiered approach should be used to assess population trends: 1) the long-term trend should be estimated across all years of data beginning with Fall 2001, and 2) short-term population changes should be calculated to capture catastrophic events, which may trigger immediate management action.

Information Needs and Adaptive Management

Criteria 1A, 1B, 2A, and 2B are based on observed and assumed historical habitat conditions and population numbers. These numbers could be revised through a PVA incorporating current and projected population numbers and habitat availability, which would be collected through monitoring red squirrel population numbers and assessing the results of management actions designed to improve or restore red squirrel habitat. Wood (2007) developed a PVA for the Mount Graham red squirrel using demographic factors, habitat characteristics, and threats specific to the Mount Graham red squirrel population. He modified Rushton *et al*.'s (2006) population model by including current habitat quality as evaluated from high-resolution satellite imagery (Wood *et al*. 2007), which allowed him to account for variation in midden quality as the age and composition of trees surrounding middens changed available resources. For conservation and management purposes, using and modifying Wood's model to incorporate new information on the effects of habitat managment, in addition to the extent and possible management of predation and interspecific competition, would allow us to capture changes in habitat quality due to disturbance and management scenarios and relate these to population processes. Having a model that combines Mount Graham red squirrel-specific demographic, predation, competition, and habitat information will permit us to manipulate the model to imitate plausible scenarios of management activities, habitat change, and threat abatement. This inclusive model, in turn, will allow us to evaluate the effects on the Mount Graham red squirrel population over the long term (100 years), and ultimately to fine tune the population numbers in the recovery criteria.

Additionally, little is known about the husbandry needs of tree squirrels in general, and red squirrels specifically, in captivity. Husbandry techniques should be developed with up to 16 individuals (as advised by the Recovery Team) to determine how to breed Mount Graham red squirrels in captivity, should the need arise to establish a captive population. The captive population can serve as a buffer in case of catastrophic habitat loss due to stochcastic events, which is currently one of the greatest threats to the Mount Graham red squirrel. A Population Management Plan (PMP) and associated Stud Book have been developed to guide this program, and a PMP Coordinator is in place to direct it (Stuart Wells, Director of Conservation and Science, The Phoenix Zoo, pers. comm. 2010). Additionally, public information about the recovery program should be developed at zoological institutions, which may include (but not be limited to) creating informational kiosks, exhibiting red squirrels, and providing photos and video of captive-rearing efforts to the press and management agencies for eductational use. Partnerships with zoos and captive facilities are being pursued; coordinating with these partners should continue.

Outline for Mount Graham Red Squirrel Recovery Actions

1. Protect and manage existing habitat and population.

1.1. Employ methods and management actions to maintain Mount Graham red squirrel habitat.
    1.1.1. As appropriate and supported by research (see 3.5.), apply methods developed to control outbreaks of insects and pathogens that cause widespread damage of the remaining conifer forests (*Listing Factor A*).
    1.1.2. Work with Arizona Game and Fish Department to control or eliminate Abert's squirrels in the Pinaleño Mountains, as appropriate and supported by research (see 3.4.) (*Listing Factors A, E*).
    1.1.3. Work with Arizona Game and Fish Department to control or eliminate non-native ungulates in the Pinaleño Mountains, as appropriate and supported by monitoring (see 5.7.) (*Listing Factors A, E*).
    1.1.4. Work with project proponents and lead Federal agencies to minimize, to the maximum extent practicable, effects of future developments on the Mount Graham red squirrel and its habitat (*Listing Factor A*).
    1.1.5. Develop and implement a long-term management plan, ensuring Mount Graham red squirrel habitat is managed and maintained in perpetuity (*Listing Factors A, D*).

1.2. Maintain a population level of Mount Graham red squirrels sufficient to ensure the species' persistence.
    1.2.1. Maintain and continue to enforce current vehicle speed restrictions to reduce Mount Graham red squirrel roadkills (*Listing Factor E*).
    1.2.2. Maintain and continue enforcement of Arizona Game and Fish Department's statute prohibiting the hunting of Mount Graham red squirrel (*Listing Factor E*).
    1.2.3. Implement methods to reduce predation on the Mount Graham red squirrel, if appropriate and supported by research (see 3.2. and 3.3.) (*Listing Factor C*).
    1.2.4. Implement a captive breeding program based on the results of research (see 3.11-3.13), if necessary to conserve genetic stock or for production of animals for reestablishment, as appropriate (*Listing Factor E*).

2. Restore and create habitat to allow for the existence of a viable and robust population.

    2.1. Complete planning for and implementation of the Pinaleño Ecosystem Restoration Project, which will have as an objective, conservation of Mount Graham red squirrel habitat (*Listing Factor A*).
    2.2. Plant conifers of value to the Mount Graham red squirrel in areas impacted by recent fires and insect damage, including West Peak, if necessary (*Listing Factor A*).
    2.3. Plant trees of value to the Mount Graham red squirrel in areas between West Peak and the main population to enhance connectivity and dispersal habitat (*Listing Factor A*).
    2.4. Return developed areas to habitat for Mount Graham red squirrel, as appropriate and supported by research (see 3.6. and 3.7.) (*Listing Factor A*).

3. Research the conservation biology of the Mount Graham red squirrel with the objective of facilitating efficient recovery.

3.1. Research the habitat requirements of the Mount Graham red squirrel during all life stages throughout the potential range in the Pinaleño Mountains (*Listing Factors A, E*).
3.2. Investigate and analyze the impact of avian predation on Mount Graham red squirrels. (*Listing Factor C*).
3.3. Investigate and analyze the impact of mammalian predation on Mount Graham red squirrels (*Listing Factor C*).
3.4. Investigate and analyze the effects of Abert's squirrels on Mount Graham red squirrels, including the possibility of reducing and/or eliminating the threat to the squirrel due to competition with the Abert's squirrel (*Listing Factor E*).
3.5. Investigate methods, including forest management measures, to control outbreaks of insects and pathogens that could cause widespread damage to the remaining forest within Mount Graham red squirrel habitat (*Listing Factor A*).
3.6. Investigate the impact of the Columbine Summer Home and Bible Camp areas on habitat use by Mount Graham red squirrels (*Listing Factors A, E*).
3.7. Evaluate options for returning developed areas to habitat for the Mount Graham red squirrel (*Listing Factor A*).
3.8. Investigate habitat availability on West Peak and habitat connectivity to the main population, as well as Mount Graham red squirrel presence on West Peak (*Listing Factor A*).
3.9. Continue to collect remains of Mount Graham red squirrels for use in further research (*Listing Factor E*).
3.10. Conduct Population Viability Analysis for the Mount Graham red squirrel to inform the recovery criteria and develop scenarios for future management (*Listing Factors A, C, E*).
3.11. Determine captive husbandry needs of the Mount Graham red squirrel with up to a total of 16 Mount Graham red squirrels (*Listing Factor E*).
3.12. Design a captive breeding and repatriation program for Mount Graham red squirrel, which may include rotating animals in and out of the captive facility to increase genetic diversity and limit the opportunity for genetic adaptations to captive conditions (*Listing Factor E*).
3.13. Locate funding and partners to implement the captive breeding and repatriation program (*Listing Factor E*).

4. Develop support and build partnerships to facilitate recovery.

4.1. Hold annual meetings of the Technical and Stakeholder teams of the Recovery Team to review progress and develop work plans for future work (*Listing Factors A, C, E*).
4.2. Meet regularly with the Pinaleño Partnerships to update them on the recovery effort and seek their input (*Listing Factors A, C, E*).
4.3. Develop public information about the recovery program at zoological institutions, which may include (but not be limited to) informational kiosks, exhibiting red squirrels, and providing photos and video of captive-rearing efforts to the press and management agencies for eductational use (*Listing Factor E*).

5. Monitor progress and practice adaptive management in which the recovery plan and management actions are revised to reflect new information developed through research and monitoring.

    5.1. Monitor and track area of available habitat within the range of the Mount Graham red squirrel in accordance with Appendix C (*Listing Factor A*).
    5.2. Continue rangewide Mount Graham red squirrel population monitoring at least once per year to track population trends, in accordance with Appendix A (*Listing Factor E*).
    5.3. If implemented, monitor the progress of the captive breeding and repatriation program (*Listing Factor E*).
    5.4. Monitor the progress towards establishing a population of Mount Graham red squirrels on West Peak (*Listing Factor E*).
    5.5. Monitor the effects of predation on the Mount Graham red squirrel (*Listing Factor C*).
    5.6. Monitor the population and distribution of Abert's squirrels in the Pinaleño Mountains and its effects on the Mount Graham red squirrel (*Listing Factor E*).
    5.7. Monitor the effects of browsing by ungulates in the Pinaleño Mountains (*Listing Factor A*).
    5.8. Continue to monitor insects and pathogens in the Pinaleño Mountains (*Listing Factor A*).
    5.9. Compile an annual report that will track recovery progress and propose needed work (*Listing Factors A, C, E*).
    5.10. During annual meetings of the Recovery Team, review monitoring and research data and make recommendations to revise the recovery strategy, criteria, and actions as appropriate (*Listing Factors A, C, E*).

Narrative Outline for Mount Graham Red Squirrel Recovery Actions

1. Protect and manage existing habitat and population.

    1.1. Employ methods and management actions to maintain Mount Graham red squirrel habitat.

        1.1.1. As appropriate and supported by research (see 3.5.), apply methods developed to control outbreaks of insects and pathogens that cause widespread damage of the remaining conifer forests (*Listing Factor A*).
        Monitoring of insect infestations in the Pinaleño Mountains should continue. The Recovery Team will work with the USFS to determine the appropriate use and application of insect management techniques for species known to cause extensive tree mortality. Implementation of the Pinaleño Ecosystem Restoration Project (see 2.1.) will help to restore healthy stand densities in the mixed conifer forest, which should translate to these stands being less prone to stress and insect infestation.

        1.1.2. Work with Arizona Game and Fish Department to control or eliminate Abert's squirrels in the Pinaleño Mountains, as appropriate and supported by research (see 3.4.) (*Listing Factors A, E*).

It likely will be impossible to completely eliminate Abert's squirrels in the Pinaleño Mountains, as parts of the mountain range are extremely rugged and inaccessible to humans. However, it may be appropriate to target areas for Abert's squirrel elimination or control to protect and maintain habitat important for the Mount Graham red squirrel. Based on results of research (see 3.4.), actions to control Abert's squirrels, such as establishing special Abert's squirrel hunts that do not significantly increase human presence in Mount Graham red squirrel territory, should be evaluated and implemented as appropriate.

1.1.3. Work with Arizona Game and Fish Department to control or eliminate non-native ungulates in the Pinaleño Mountains, as appropriate and supported by monitoring (see 5.7.) (*Listing Factors A, E*).
Ungulates can severely impact the growth of tree seedlings and saplings when populations are high. Browsing should be monitored in the Pinaleños Mountains to ensure non-native ungulate activity is not impacting red squirrel habitat (see 5.7). Actions to reduce browsing should be taken if monitoring indicates impacts to habitat are occurring.

1.1.4. Work with project proponents and lead Federal agencies to minimize, to the maximum extent practicable, effects of future developments on the Mount Graham red squirrel and its habitat (*Listing Factor A*).
There is a possibility that unpaved sections of Swift Trail could be paved in the future. This project may also include improvements to Swift Trail at lower elevations that would affect the numbers and sizes of vehicles accessing the upper elevations, including red squirrel habitat. Additionally, the 1988 Biological Opinion for the Mount Graham Astrophysical Area Plan includes proposed plans to build seven telescopes (there are currently three), logistics buildings, support facilities, a buried powerline, sewage leach fields, utility fields, and public parking and picnic areas. The construction of new facilities will require review through and compliance with the National Environmental Policy Act, as well as a new consultation pursuant to the Act with the USFWS. As planning for these and other projects progresses, USFWS, USFS, and AGFD will work closely with the project proponents to minimize their impacts to the Mount Graham red squirrel and its habitat.

1.1.5. Develop and implement a long-term management plan, ensuring Mount Graham red squirrel habitat is managed and maintained in perpetuity (*Listing Factors A, D*).
Research should continue to be conducted in the Pinaleño Mountains to determine red squirrel demographic and habitat characteristics (discussed in the Habitat Characteristics section). The results of this research should be incorporated into the annual report (5.7.).

1.2. Maintain a population level of Mount Graham red squirrels sufficient to ensure the species persistence.

1.2.1. Maintain and continue to enforce current vehicle speed restrictions to reduce Mount Graham red squirrel roadkills (*Listing Factor E*).
Speed restrictions within Mount Graham red squirrel habitat should not be allowed to increase. There is a possibility that portions or all of the unpaved sections of Swift Trail could be paved in the future. Should this happen, speed limits should not be allowed to increase, and careful monitoring of red squirrel roadkills will be necessary.

1.2.2. Maintain and continue enforcement of Arizona Game and Fish Department's statute prohibiting the hunting of Mount Graham red squirrel (*Listing Factor E*).
Continue prohibiting hunting of Mount Graham red squirrels.

1.2.3. Implement methods to reduce predation on the Mount Graham red squirrel, if appropriate and supported by research (see 3.2. and 3.3.) (*Listing Factor C*).
Methods to control predation on the Mount Graham red squirrel should be implemented, if appropriate and supported by research (see 3.2. and 3.3.).

1.2.4. Implement a captive breeding program based on the results of research (see 3.11.-3.13.), if necessary to conserve genetic stock or for production of animals for reestablishment, as appropriate (*Listing Factor E*).
Little is known about the husbandry needs of tree squirrels in general, and red squirrels specifically, in captivity. Husbandry techniques should be developed with up to 16 individuals (as advised by the Recovery Team) to determine how to breed Mount Graham red squirrels in captivity, should the need arise to establish a captive population.

2. Restore and create habitat to allow for the existence of a viable and robust population.

2.1. Complete planning for and implementation of the Pinaleño Ecosystem Restoration Project, which will have as an objective, conservation of Mount Graham red squirrel habitat (*Listing Factor A*).
The Pinaleño Ecosystem Restoration Project (PERP) is a 10-year project designed to improve the health of the mixed conifer forest on Mount Graham by returning the area to stand densities closer to those found before the impacts of grazing and fire-suppression dominated the landscape. With the over-arching goal designed to protect and promote habitat for the Mount Graham red squirrel, this fuels reduction project will decrease the risk of catastrophic fire in spruce-fir and mixed-conifer areas to maintain key biomes favored by the Mount Graham red squirrel. This project is currently undergoing formal consultation; once completed, implementation will occur during the following 10 years.

2.2. Plant conifers of value to the Mount Graham red squirrel in areas impacted by recent fires and insect damage, including Forest Service roads and West Peak, if necessary (*Listing Factor A*).
Seed dispersal into areas impacted by fire and insect damage can be problematic if seed trees have been destroyed. During the late summer of 2007, the Coronado National

Forest began a project to plant seedlings of corkbark fir, Engelmann spruce, and Douglas-fir on approximately 202 ha (500 ac) within the portions of the Mount Graham red squirrel refugium that were burned at the highest intensities during the Nuttall Complex wildfire of 2004. The project will take place over the course of the next 5-7 years, and will be implemented as seedlings and volunteers are available. The trees planted during this project should be monitored to determine the viability of tree planting projects in the future. The results of the monitoring should be used to design and implement additional plantings to reestablish red squirrel habitat, including Forest Service roads (such as FR 507 and 669) and West Peak if, after investigating current habitat conditions near the roads and on the peak, it is determined that tree planting is necessary (see 3.8.).

2.3. Plant trees of value to the Mount Graham red squirrel in areas between West Peak and the main population to enhance connectivity and dispersal habitat (*Listing Factor A*).
Based on results from 3.8., appropriate tree species should be planted between West Peak and the main population to enhance connectivity between these two areas.

2.4. Return developed areas to habitat for Mount Graham red squirrel, as appropriate and supported by research (*Listing Factor A*).
Research is recommended to determine the impact of human development on the Mount Graham red squirrel (see 3.6. and 3.7.). If results show an adverse impact, options should be developed, evaluated, and implemented to minimize and/or mitigate this impact.

3. Research the conservation biology of the Mount Graham red squirrel with the objective of facilitating efficient recovery.

3.1. Research the habitat requirements of the Mount Graham red squirrel during all life stages throughout the potential range in the Pinaleño Mountains (*Listing Factors A*, *E*).
Research should continue to be conducted in the Pinaleño Mountains to determine red squirrel demographic and habitat characteristics. The results of this research should be incorporated into the annual report (see 5.7.).

3.2. Investigate and analyze the impact of avian predation on Mount Graham red squirrels (*Listing Factor C*).
A study should be designed and conducted to determine the extent of avian predation tolerance or avoidance by the Mount Graham red squirrel, and what, if any, methods are available to manage accordingly.

3.3. Investigate and analyze the impact of mammalian predation on Mount Graham red squirrels (*Listing Factor C*).
A study should be designed and conducted to determine the extent of mammalian predation tolerance and avoidance by the Mount Graham red squirrel, and what, if any, methods are available to manage accordingly.

3.4. <u>Investigate and analyze the effects of Abert's squirrels on Mount Graham red squirrels, including the possibility of reducing and/or eliminating the threat to the squirrel due to competion with the Abert's squirrel (*Listing Factor E*).</u>
It will be impossible to completely eliminate Abert's squirrels in the Pinaleño Mountains, as parts of the mountain range are extremely rugged and inaccessible to humans. However, it may be appropriate to target areas for Abert's squirrel control during important life cycles of the Mount Graham red squirrel. A study should be designed and conducted to assess the impacts of Abert's squirrels on resources within Mount Graham red squirrel habitat. If it is determined the impact of Abert's squirrels on the red squirrel is great and management to control them (most likely in targeted areas) is an option, then information gained in this effort should be used to design and implement an Abert's squirrel control program.

3.5. <u>Investigate methods, including forest management measures, to control outbreaks of insects and pathogens that could cause widespread damage to the remaining forest within Mount Graham red squirrel habitat (*Listing Factor A*).</u>
The potential for insect outbreaks in remaining red squirrel habitat should be evaluated. Research should be conducted to determine if this potential can be reduced and by what methods.

3.6. <u>Investigate the impact of the Columbine Summer Home and Bible Camp areas on habitat use by Mount Graham red squirrels (*Listing Factors A, E*).</u>
A study investigating the impacts of human activity on Mount Graham red squirrels should be designed and conducted to determine the effects of the summer homes near Columbine and the Bible Camp have on the red squirrel.

3.7. <u>Evaluate options for returning developed areas to habitat for the Mount Graham red squirrel (*Listing Factor A*).</u>
Based on the results of 3.6., options for returning developed areas to habitat for the Mount Graham red squirrel should be evaluated, including economic and logistical impacts.

3.8. <u>Investigate habitat availability and Mount Graham red squirrel presence on West Peak (*Listing Factor A*).</u>
Anecdotal evidence suggests Mount Graham red squirrels may be present on West Peak. This should be investigated and the habitat currently available on West Peak, dispersal habitat between the West Peak and the main population, and possibilities for habitat enhancement should be assessed.

3.9. <u>Continue to collect remains of Mount Graham red squirrels for use in further research (*Listing Factors C, E*).</u>
As squirrel carcasses are collected, they should be necropsied to determine if they have diseases and/or parasites, and should be evaluated for their reproductive condition, amount of fat, analysis of contaminants analysis, and other information that can be gathered, including samples for genetic analysis.

3.10. Conduct Population Viability Analysis for the Mount Graham red squirrel to inform the recovery criteria and develop scenarios for future management (*Listing Factors A, C, E*).
Work with Wood (2007) and/or other researchers to refine his PVA to include current habitat and population conditions, as well as the IUCN standards for Endangered (downlisting criterion) and Vulnerable (delisting criterion). Once several years of monitoring are completed and research and management are underway, the model will be re-run to incorporate these changes. Additionally, stakeholders and technical experts will be involved to test and evaluate various management scenarios with PVA models in order to select the scenarios that are most effective at recovery while taking into account social, economic, and political constraints.

3.11. Determine captive husbandry needs of the Mount Graham red squirrel with up to a total of 16 squirrels (*Listing Factor E*).
Up to a total of 16 Mount Graham red squirrels should be brought into captivity to begin the process of determining captive husbandry techniques. USFWS, AGFD, and the UA will work closely with these facililites to ensure capture of these squirrels will not affect the overall population.

3.12. Design a captive breeding and repatriation program for Mount Graham red squirrel, which may include rotating animals in and out of the captive facility to increase genetic diversity and limit the opportunity for genetic adaptations to captive conditions (*Listing Factor E*).
A qualified individual or organization will develop a captive breeding and repatriation program for the Mount Graham red squirrel, including developing a Population Management Program or Species Survival Plan, as well as a Stud Book specific to the Mount Graham red squirrel. USFWS is currently working with the Phoenix Zoo, Arizona-Sonora Desert Museum, Reid Park Zoo, and Miller Park Zoo to begin this process. Genetic analysis will need to be conducted on each individual in the captive breeding and repatriation program to update and maintain the Stud Book.

3.13. Locate funding and partners to implement the captive breeding and repatriation program (*Listing Factor E*).
Once design of the captive breeding and repatriation plan is completed, funding and partners will be sought to implement the program. This includes locating partners with experience in carrying out such programs (e.g. zoos).

4. Develop support and build partnerships to facilitate recovery.

4.1. Hold annual meetings of the Technical and Stakeholder teams of the Recovery Team to review progress to date and work plans for future work (*Listing Factors A, C, E*).
A joint meeting of the Technical and Stakeholders teams of the Recovery team should be held annually or more frequently (if necessary) to review the current status of the Mount Graham red squirrel, assess recovery plan accomplishments, develop work plans for the next fiscal year, and discuss needed adaptive management.

4.2. Meet regularly with the Pinaleño Partnership to update them on the recovery effort and seek their input (*Listing Factors A*, *C*, *E*).
The Pinaleño Partnership includes Federal and state agencies, summer home owners, elected officials, and other parties who are interested in forest health issues in the Pinaleño Mountains. Coordination and outreach through the Pinaleño Partnership will be pursued to inform the public of this recovery plan and to include public input into recovery implementation.

4.3. Develop public information about the recovery program at zoological institutions, which may include (but not be limited to) informational kiosks, exhibiting red squirrels, and providing photos and video of captive-rearing efforts to the press and management agencies for eductational use (*Listing Factor E*).
Mount Graham red squirrels may be either on or off exhibit at zoological institutions participating in the recovery program. In either case, public information programs should be developed to provide important information on Mount Graham red squirrel recovery efforts. For example, at institutions where red squirrels are kept off exhibit, information on the captive breeding program could be displayed on informational kiosks to keep the public informed on the progress of the red squirrel recovery effort. At facilities where red squirrels are on exhibit, this information should be provided at the exhibit. Additionally, photos and video of the captive program should be developed and made available to keep the public informed and management agencies supplied with Mount Graham red squirrel captive-rearing educational information.

5. Monitor progress and practice adaptive management in which the recovery plan and management actions are revised to reflect new information developed through research and monitoring.

5.1. Monitor and track area of available habitat within the range of the Mount Graham red squirrel in accordance with Appendix C (*Listing Factor A*).
Available Mount Graham red squirrel habitat will be determined through a combination of satellite imagery analysis and ground truthing, as outlined in Appendix C. Because habitat responds slowly to management actions, imagery should be collected and analyzed, at a minimum, every 5 years or after a major habitat-altering event (if the event occurs between 5-year periods), to determine the status of restored and maintained habitat.

5.2. Continue rangewide Mount Graham red squirrel population monitoring at least once per year to track population trends, in accordance with Appendix A (*Listing Factor E*).
Annual mountainwide censuses for the Mount Graham red squirrel provide estimates of the population size over time, showing trends in the population due to deterministic and stochastic events. A census occurring at least once per year following standardized survey methods should be continued to provide information on red squirrel population numbers and trends.

5.3. If implemented, monitor the progress of the captive breeding and repatriation program (*Listing Factor E*).

As partners and funding are located to develop the captive breeding and repatriation program, information detailing each year's progress should be included in the final report.

5.4. Monitor the progress toward establishing a population of Mount Graham red squirrels on West Peak (*Listing Factor E*).
As habitat becomes available on West Peak and dispersal corridors are delineated, monitoring the progress toward and establishment of a red squirrel metapopulation on this peak will be conducted.

5.5. Monitor the effects of predation on the Mount Graham red squirrel (*Listing Factor C*).
Mammalian, and particularly, avian predators may constitute the majority of the mortality experienced by Mount Graham red squirrels. A plan to monitor and, if feasible, manage the effects of predation on the Mount Graham red squirrel will be developed.

5.6. Monitor the population and distribution of Abert's squirrels in the Pinaleño Mountains and its effects on the Mount Graham red squirrel (*Listing Factor E*).
A monitoring plan for Abert's squirrels will be incorporated into the Pinaleño Ecosystem Restoration Project to record the effects of silvicultural treatments on Abert's squirrel distribution and abundance. Based on the monitoring data, targeted control projects may need to be implemented to reduce or eliminate Abert's numbers in selected areas to benefit the Mount Graham red squirrel.

5.7. Monitor the effects of browsing by ungulates in the Pinaleño Mountains (*Listing Factor A*).
Ungulates, such as Rocky Mountain elk, can severely impact the growth of tree seedlings and saplings when populations are high. Browsing should be monitored in the Pinaleño Mountains to ensure ungulate activity is not impacting red squirrel habitat. Actions to reduce browsing should be taken if monitoring indicates impacts to habitat are occurring.

5.8. Continue to monitor insects and pathogens in the Pinaleño Mountains (*Listing Factor A*).
Insects and pathogens should continue to be monitored in the Pinaleño Mountains to inform the need to implement control measures for them and to monitor the health of the forest.

5.9. Compile an annual report that will track recovery progress and propose needed work (*Listing Factors A, C, E*).
Annual progress reports should be produced by the recovery team (Technical and Stakeholders teams). The reports should summarize: (1) recovery plan implementation for the previous year (including monitoring results; see actions 5.2 through 5.8), (2) work plans for the upcoming year, and (3) recommended changes to recovery implementation (see action 5.10). A copy of this report should be provided to the Recovery Team for review prior to their meetings (4.1.).

5.10. During annual meetings of the Recovery Team, review monitoring and research data and make recommendations to revise the recovery strategy, criteria, and actions as appropriate (*Listing Factors A*, *C*, *E*).

Adaptive management is a process whereby the recovery plan is revised based on relevant new information suggesting that recovery can be achieved more efficiently or sooner if the recovery strategy, actions, or other elements of the plan are revised. The results of monitoring, research, PVA, and Recovery Team meetings will track plan implementation and provide potentially new or revised management approaches to facilitate recovery. Any aspect of the recovery plan may need to be revised to include or adapt to this information.

PART III. IMPLEMENTATION SCHEDULE

The implementation schedule outlines the tasks discussed in Part II and indicates task numbers, priorities, durations, estimated costs, and partners that may be involved in implementing the task. If accomplished, these tasks should enable the Mount Graham red squirrel to be downlisted or delisted. The costs for each task are estimates, and actual budgets will have to be determined when each task is undertaken. Recovery plans are non-regulatory documents, and as such, identified partners are not obligated to implement recovery tasks. Cost estimates do not commit funding by any agency.

Action priorities in the implementation schedule are assigned as follows:

Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

Priority 2: An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to provide for full recovery of the species.

Priorities are based in part on the immediacy and severity of specific threats, and how each recovery action would ameliorate those threats. Task duration in Column 4 indicates the number of years required to complete the task. A continuing task will continue to be conducted once implemented. An ongoing task is one that is already being conducted.

The following abbreviations are used to indicate the responsible party for a given action. Cooperating parties are shown in parentheses.

AGFD	Arizona Game and Fish Department
USFS	U.S. Forest Service – Coronado National Forest
FWS-ES	U.S. Fish and Wildlife Service – Ecological Services, Tucson
GCSD	Graham County Sheriff's Department
RES	Researchers from AGFD, USFS, Universities, Forest Service Range and Experiment Stations, etc.
SSG	Stakeholders Subgroup of the Recovery Team
TSG	Technical Subgroup of the Recovery Team

IMPLEMENTATION SCHEDULE

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
					Costs (thousands of dollars)						
1.1.1	As appropriate and supported by research (see 3.5.), apply methods developed to control outbreaks of insects and pathogens that cause widespread damage of the remaining conifer forests.	3	Continuing	CNF	10	10	10	10	10	Extending 50 or more years	50
1.1.2	Work with Arizona Game and Fish Department to control or eliminate Abert's squirrels in the Pinaleño Mountains, as appropriate and supported by research (see 3.4.).	2	Continuing	AGFD	25	25	25	25	25	Extending 50 or more years	125
1.1.3	Work with Arizona Game and Fish Department to control or eliminate non-native ungulates in the Pinaleño Mountains, as appropriate and supported by monitoring (see 5.7.).	3	Continuing	AGFD	5	5	5	5	5	Extending 50 or more years	25
1.1.4	Work with project proponents and lead Federal agencies to minimize to the maximum extent practicable, effects of future developments on the Mount Graham red squirrel and its habitat.	1	Continuing	FWS-ES CNF AGFD	5 10 1	5 10 1	5 10 1	5 10 1	5 10 1	Extending 50 or more years	25 50 5
1.1.5	Develop and implement a long-term management plan, ensuring Mount Graham red squirrel habitat is managed and maintained in perpetuity.	1	Continuing	AGFD CNF FWS-ES	10 15 5	10 15 5	10 15 5	10 15 5	10 15 5	Extending 50 or more years	50 75 25

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
1.2.1	Maintain and continue to enforce current vehicle speed restrictions to reduce Mount Graham red squirrel roadkills.	1	Continuing	GCSD CNF	5 5	5 5	5 5	5 5	5 5	No change from current condition	25 25
1.2.2	Maintain and continue enforcement of Arizona Game and Fish Department's statute prohibiting the hunting of Mount Graham red squirrel.	1	Continuing	AGFD	1	1	1	1	1	No change from current condition	5
1.2.3	Implement methods to reduce predation on the Mount Graham red squirrel, if appropriate and supported by research (see 3.2. and 3.3.).	2	Continuing	AGFD RES CNF FWS-ES	0 0 0 0 97	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	Action would begin in FY 6 after research actions 3.2. and 3.3. are completed. This action would extend for 50 or more years thereafter.	0 0 0 0
1.2.4	Implement a captive breeding program based on the results of research (see 3.11.-3.13.), if necessary to conserve genetic stock or for production of animals for reestablishment, as appropriate.	1	50 years	FWS-ES RES CNF AGFD	0 0 0 0	0 0 0 0	0 0 0 0	5 25 5 5	5 25 5 5	After pilot program, full program is implemented if deemed necessary.	10 50 10 10
2.1	Complete planning for and implementation of the Pinaleño Ecosystem Restoration Project, which will have as an objective, conservation of Mount Graham red squirrel habitat.	1	11 years	CNF	20	50	50	50	50	$20K for 1 year, $50K for 10 years	220

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
2.2	Plant conifers of value to the Mount Graham red squirrel in areas impacted by recent fires and insect damage, including West Peak, if necessary.	3	5 years	CNF	10	10	10	10	10		50
2.3	Plant trees of value to the Mount Graham red squirrel in areas between West Peak and the main population to enhance connectivity and dispersal habitat.	2	5 years	CNF	10	10	10	10	10		50
2.4	Return developed areas to habitat for Mount Graham red squirrel, as appropriate and supported by research (see 3.6. and 3.7.).	2	Continuing	FWS-ES CNF TSG SSG AGFD	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	0 0 0 0 0	Action would begin in FY 6 after research action 5.6. is completed. This action would extend for 50 or more years thereafter.	0 0 0 0 0
3.1	Research the habitat requirements of the Mount Graham red squirrel during all life stages throughout the potential range in the Pinaleño Mountains.	1	5 years	RES	33	33	33	33	33		165
3.2	Investigate and analyze the impact of avian predation on Mount Graham red squirrels.	1	5 years	RES CNF	33 5	33 5	33 5	33 5	33 5		165 25
3.3	Investigate and analyze the impact of mammalian predation on Mount Graham red squirrels.	1	5 years	RES CNF	33 5	33 5	33 5	33 5	33 5		165 25

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
3.4	Investigate and analyze the effects of Abert's squirrels on Mount Graham red squirrels, including the possibility of reducing and/or eliminating the threat to the squirrel due to competion with the Abert's squirrel.	1	3 years	RES CNF	33 5	33 5	33 5	0 0	0 0		99 15
3.5	Investigate methods, including forest management measures, to control outbreaks of insects that could cause widespread damage to the remaining forest within Mount Graham red squirrel habitat.	3	5 years	RES CNF	10 5	10 5	10 5	10 5	10 5		50 25
3.6	Investigate the impact of the Columbine Summer Home and Bible Camp areas on habitat use by Mount Graham red squirrels.	2	5 years	RES CNF FWS-ES	33 5 1	33 5 1	33 5 1	33 5 1	33 5 1		165 25 5
3.7	Evaluate options for returning developed areas to habitat for the Mount Graham red squirrel.	2	5 years	RES CNF FWS-ES	33 5 1	33 5 1	33 5 1	33 5 1	33 5 1		165 25 5
3.8	Investigate habitat availability and Mount Graham red squirrel presence on West Peak.	1	1 year	RES FWS-ES CNF AGFD	1 1 1 1	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0		1 1 1 1

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
3.9	Continue to collect remains of Mount Graham red squirrels for use in further research.	2	Continuing	RES FWS-ES CNF AGFD	<1 <1 <1 <1	<1 <1 <1 <1	<1 <1 <1 <1	<1 <1 <1 <1	<1 <1 <1 <1	Some minimal cost is assumed to collect and house red squirrel remains.	1 1 1 1
3.10	Conduct Population Viability Analysis for the Mount Graham red squirrel to inform the recovery criteria and develop scenarios for future management.	1	1 year	RES FWS-ES TSG SSG	10 1 0 0	0 0 0 0	0 0 0 0	0 0 0 0	0 0 0 0	Additional costs may be incurred in later years if PHVA is conducted.	10 1 0 0
3.11	Determine captive husbandry needs of the Mount Graham red squirrel with up to a total of 16 Mount Graham red squirrels.	1	5 years	RES	40	40	40	40	40	$10K to each of 4 facilities for 3 years	200
3.12	Design a captive breeding and repatriation program for Mount Graham red squirrel, which may include rotating animals in and out of the captive facility to increase genetic diversity and limit the opportunity for genetic adaptations to captive conditions.	1	5 years	RES	15	15	15	15	15	Includes genetic analysis of captive squirrels (to maintain Stud Book).	75
3.13	Locate funding and partners to implement the captive breeding and repatriation program.	1	5 years	FWS-ES RES	2 3	2 3	2 3	2 3	2 3	Office time spent seeking partners and funding.	10 15

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
4.1	Hold annual meetings of the Technical and Stakeholder teams of the Recovery Team to review progress to date and develop work plans for future work.	1	Continuing	FWS-ES SSG TSG	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	Extending 50 or more years	5 5 5
4.2	Meet regularly with the Pinaleño Partnerships to update them on the recovery effort and seek their input.	1	Continuing	FWS-ES SSG TSG	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	Extending 50 or more years	5 5 5
4.3	Develop public information about the recovery program at zoological institutions, which may include (but not be limited to) informational kiosks, exhibiting red squirrels, and providing photos and video of captive-rearing efforts to the press and management agencies for eductational use.	1	5 years	FWS-ES RES	2 10	2 10	2 10	2 10	2 10		10 50
5.1	Monitor and track area of available habitat within the range of the Mount Graham red squirrel in accordance with Appendix C.	1	Continuing	RES CNF FWS-ES	12 1 1	0 0 0	0 0 0	0 0 0	0 0 0	Acquire and analyze satellite imagery every 5 years, or after a major stochastic event (whichever is shorter), for 50 or more years.	12 1 1

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
5.2	Continue rangewide Mount Graham red squirrel population monitoring at least once per year to track population trends, in accordance with Appendix A.	1	Continuing	AGFD CNF FWS-ES	10 15 5	10 15 5	10 15 5	10 15 5	10 15 5	Extending 50 or more years	50 75 25
5.3	If implemented, monitor the progress of the captive breeding and repatriation program.	2	Continuing	RES	0	0	0	TBD	TBD	Captive breeding would begin after husbandry needs are determined and plan is developed (3.11.-13.), if approved by the Recovery Team.	TBD
5.4	Monitor the progress towards establishing a population of Mount Graham red squirrels on West Peak.	1	Continuing	FWS-ES CNF AGFD	0 0 0	1 1 1	1 1 1	1 1 1	1 1 1	If squirrels are found on West Peak, it will be added to the annual mountain-wide surveys.	4 4 4
5.5	Monitor the effects of predation on the Mount Graham red squirrel.	1	5 years	RES CNF	33 5	33 5	33 5	33 5	33 5		165 25
5.6	Monitor the population and distribution of Abert's squirrels in the Pinaleño Mountains and its effects on the Mount Graham red squirrel.	1	Continuing	CNF AGFD	0 0	10 5	10 5	10 5	10 5	Begin monitoring when PERP begins and continue for 10 years.	40 20

Task	Description	Priority	Duration	Responsible Party	FY 1	FY 2	FY3	FY 4	FY 5	Comments[1]	Total
5.7	Monitor the effects of browsing by ungulates in the Pinaleño Mountains.	2	Continuing	FWS-ES CNF AGFD	1 1 1	1 1 1	1 1 1	1 1 1	1 1 1	If ungulates are negatively affecting red squirrel habitat, implement recovery action 1.1.3.	5 5 5
5.8	Continue to monitor insects and pathogens in the Pinaleño Mountains.	1	Continuing	CNF	5	5	5	5	5	Extending 50 or more years	25
5.9	Compile an annual report that will track recovery progress and propose needed work.	1	Continuing	FWS-ES TSG SSG	1 0 0	1 0 0	1 0 0	1 0 0	1 0 0	Extending 50 or more years	5 0 0
5.10	During annual meetings of the Recovery Team, review monitoring and research data and make recommendations to revise the recovery strategy, criteria, and actions as appropriate.	1	Continuing	SSG TSG RES CNF AGFD FWS-ES	1 1 1 1 1 1	1 1 1 1 1 1	1 1 1 1 1 1	1 1 1 1 1 1	1 1 1 1 1 5	Every 5 years update recovery program. Minor changes may be made annually.	5 5 5 5 5 9

FY Totals……………………………………………………………………… …567 586 586 588 592
Grand Total………………………………………………………………………………………$2,919,000.00

These totals are minimum cost estimates that do not include TBD costs.

[1]Annual and total costs are only provided for the first 5 years, although as indicated in the "Comments", some recovery actions are likely to continue for 50 years or more. Extended costs are discussed in the "Comments."

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Appendix A: Protocol for Rangewide Squirrel Census and Population Estimate Census

All citations can be found in the Literature Cited section above.

HISTORY

Surveys are important for managing and monitoring Mount Graham red squirrels. Not only do they provide important information about population size, they also help determine how close we are to achieving recovery goals by providing information about red squirrel habitat and history of use at each midden.

The Safford Ranger District of the Coronado National Forest organized and conducted the first Mount Graham red squirrel survey efforts. Belt transects were initially used to estimate the number of Mount Graham red squirrels (Spicer *et al*. 1985). A small number of participants from each agency (AGFD, USFS, USFWS, and the University of Arizona) conducted the 1986 and 1987 surveys. In 1988, the survey was expanded to a semiannual effort, conducted in the spring and fall. By 1990, the semiannual surveys were large and complex, multi-agency efforts, involving more than 30 people.

Since 1991 and with the advances in Global Positioning System (GPS) technology, smaller crews have been used to conduct the surveys. In 1994, survey responsibility was transferred to the AGFD Nongame Branch. Since 1996, survey coordination and data management responsibility has resided with the AGFD Region V (Tucson) Office.

Systematic searches to find new middens and to determine if existing middens have disappeared have occasionally been conducted. In 2002, AGFD began randomly selecting areas for midden sweeps.

CURRENT SAMPLING DESIGN

The current population monitoring technique was implemented by the Coronado National Forest in 1991. As more information was learned about midden locations, the current method of randomly selecting middens stratified by vegetation community became possible. Mount Graham red squirrels are found in three vegetation communities (mixed conifer, spruce-fir, and ecotone or transition between mixed conifer and spruce-fir). Because cone production differs from year to year in the three vegetation communities, which results in differing midden activity rates within these communities, midden activity is sampled by stratifying the middens by vegetation community. To enable red squirrel population estimates within a 95 percent confidence interval, survey participants visit approximately 40 percent of the known middens in each vegetation community.

Survey participants assess whether each midden visited is currently *active*, *inactive*, or *uncertain*. The assessment is based on the presence of a red squirrel at the midden; signs of recent activity such as digging, feeding, or caching cones in the midden; and the distribution and consistency of cone scales in the midden area. Participants also record any new middens that are found during the survey for future confirmation and for possible inclusion in the database should these meet the criteria of a new midden (see Survey Procedures Section). Selected areas are also systematically searched each year for new middens, which are also recorded for later evaluation.

In addition, participants classify each midden based on its physical appearance: fluffy, compacted, composted, and disappeared.

- *FLUFFY* middens show signs of current use with active digging, fresh cone scales, and, during the fall, cached cones. The midden structure is loose and airy, and the cone scales are easy to pick up and sift through your hand.
- *COMPACTED* middens usually show no signs of fresh digging, feeding, or caching activity. The cone scales may be natural orange-brown to dark in color. The midden structure is tightly packed and somewhat difficult to scoop and sift in your hand.
- *COMPOSTED* middens are partially to completely covered by non-cone debris such as needles and twigs. The cones scales are usually black and partially decomposed.
- *DISAPPEARED* middens are only identified by the presence of a tag and the flagging used to locate a midden site. There is no longer any visible evidence that a midden was present.

At the completion of the survey, the data is compiled, and two red squirrel abundance estimates are calculated. The first estimate is a conservative estimate, based on middens that were determined to be *active*. The second estimate is an optimistic estimate, as the number of *uncertain* middens is added to the number of *active* middens. A confidence interval is also calculated for the conservative and optimistic estimates. See Protocol for Determining Population Estimate section in Appendix A for formulas.

Following each survey, AGFD and the USFS report survey results to the USFWS and prepare a joint press release for the public.

SURVEY PROCEDURES

Midden surveys begin with the assignment of teams. Each team consists of a leader (someone with past survey experience) and one to two other members. Each team is assigned a group of middens along with a map showing the location of the middens that need to be visited. Team leaders pick up *Survey Packets* consisting of the maps, list of middens along with UTM locations, data forms, and extra tags for the assigned area.

Daily essentials for conducting Mount Graham red squirrel surveys include:

1. Survey Packet
2. Day pack and lunch for each person
3. 2 or 3 pencils
4. A permanent ink marker
5. Compass
6. 3 rolls of orange and black striped flagging
7. 6 to 12 aluminum nails
8. A hammer or pair of pliers
9. Binoculars
10. Geographical Positioning System (GPS) unit, if available.

LOCATING MIDDENS

Most of the known middens have been located with a Global Positioning System (GPS) unit. As a result, the midden locations are somewhat accurate and easily located using GPS units or a compass. Unique symbols on the maps indicate which middens need to be visited for the survey, and the perimeter of each particular survey area is depicted with a colored line to prevent crews from duplicating searches. The maps also show all of the known middens within the survey area to help crews navigate.

As you quietly approach the midden, look and listen for a red squirrel. One person should check the number on the metal tag to verify that it is the correct midden. *Midden sketches* are included in the survey packet and attached to the corresponding data sheet to help locate middens in which the flagging or aluminum tag is missing.

Once the midden location is verified, one person should begin filling out the *Midden Update Form* and the other crew members should search the midden for signs that indicate the presence of a red squirrel, including grass nests in the trees, nest cavities in snags, and auxillary middens. During this search, make sure that the location and tag tree are sufficiently flagged.

If a red squirrel is not seen, making clucking noises or scratching around the midden or the trunk of a nearby tree may sometimes entice movement or vocalizations. If a squirrel is present, use binoculars to determine sex and age.

Next, examine the midden for signs of recent red squirrel activity including fresh cone scales -- either green scales or brown scales without mold -- stored cones, mushrooms, fresh digging, cone cobs, and bones. Use spider webs, debris, and freshness of materials to determine signs of age. If the midden appears fluffy, and there are stored cones and signs of fresh digging and feeding, it is probably active even if a red squirrel is not seen.

If the midden tag is mutilated or missing, replace it with a new tag. Using a hammer and nail, etch the two-letter designation for the search area and the midden number on one of the extra aluminum tags in the survey packet. Place the new tag near the location of the old tag. If the tag tree has fallen, or is otherwise missing, place the new tag on the uphill side of a large (> 9 inch diameter-at-breast-height [dbh]) live tree nearest the midden center. Do not drive the aluminum nails all the way into the tree; allow some space for the tree to grow. If an old tag needs to be removed, cut the heads off the old nails with pliers, as pulling the nails out of the tree may introduce diseases.

NEWLY DISCOVERED MIDDENS

When a new or previously undiscovered old midden is found, the first step is to ensure that the midden is definitely not located on the map and there is no tagged tree in the vincinity. The team leader or group will have to use their judgment to decide if the midden represents a midden shift. If the new midden is less than 30.5 meters (100 feet) from an existing midden that is no longer in use, it is likely that the new site indicates that a resident squirrel has merely shifted the primary activity area. If it is determined to be a midden shift, the distance and direction to the new midden should be recorded on the data sheet; do not treat the midden shift as a new midden.

On the other hand, if two separate squirrels are seen at both locations, the new site should be considered as a separate midden. Mark the map as accurately as possible and record the GPS coordinates on the data sheet. Flag the midden area and place two bands of flagging around the central midden tree. Using a blank data sheet, record the date found, names of team members, and any notes that will help locate the midden. Sketch the midden area as accurately as possible; include trees, snags, logs, etc. around the midden and a north direction arrow. Also include the approximate scale and indicate the tree species and their relative size (dbh). Top view, side view, or three-dimensional views are acceptable. Do not fill in the habitat measurement; these will be done at a later date. Using the permanent ink pen, mark the flagging around the central midden tree with a new midden number. During the spring, use SP-Year-NEW-midden area-midden number (i.e. SP03NEWMP01, SP03NEWMP02, etc.). During the fall, number new middens as F-Year-NEW-midden area-midden number (i.e. F03NEWBS01, F03NEWBS02, etc.). Because juvenile red squirrels often start some middens that are quickly abandoned during the first winter, new permanent midden numbers and tags may only be placed after confirmation and addition to the database.

Before survey forms are turned in at the end of each day, the crew leader needs to review and edit them for errors, and be sure that each one is completely filled out. At the end of the survey period, all equipment and survey materials, including maps and UTM location sheets, must be returned to the survey coordinator (currently AGFD Region V Nongame Specialist).

PROTOCOL FOR DETERMINING POPULATION ESTIMATE

Note: Data in the tables below are from the Fall 2008 census, and are provided as examples for calculating population estimates and confidence intervals.

The population estimate is derived from simple formulas that use the percentage of active middens in each vegetation type found in the random sample (Table 1) and the known number of middens in each vegetation type.

I. Data summaries from the interagency cooperative survey of Mount Graham red squirrel middens and the Mount Graham red squirrel midden database:

Table 1. Data used to derive population estimate (Fall 2008 data).

Status of Midden	Number in Each Vegetation Type			
	Mixed conifer (MC)	Ecotone (EC)	Spruce-fir (SF)	Total
Active	40	97	20	157
Inactive	26	43	4	73
Uncertain	3	8	0	11
Not **F**ound	1	4	0	5
Total	70	152	24	246
n (= total Not Found)	69	148	24	241
Number in database	118	249	38	405

II. Population Estimation

A. The formulas we use to estimate the population size are as follows:

Conservative Estimate: $A_i/n_i\ (N_i) = P_i$

Optimistic Estimate: $(A_i + U_i)/n_i\ (N_i) = P_i$

Where:

A_i = the number of middens determined active in i vegetation type
U_i = the number of middens where activity is uncertain in i vegetation type
T_i = the total number of middens surveyed in i vegetation type
NF_i = the number not found in i vegetation type
n_i = the number surveyed in i vegetation type = T - NF
N_i = the total number of known middens in i vegetation type (from the database)
P_i = estimate of the total number of active middens in i vegetation type
= the estimated number of Mount Graham red squirrels in i vegetation type

B. The population estimates follow (Fall 2008 data):

Estimate	Vegetation Type			
	Mixed conifer	Ecotone	Spruce-fir	Total
Conservative	68.41	163.20	31.67	263.28
Optimistic	73.54	176.66	31.67	281.87

III. Confidence Intervals

A. The formulas used to derive the confidence intervals are as follows:

1. First, we determine the percentage of middens that are active for all vegetation types combined. We use a conservative and an optimistic estimate.

Conservative:
P = number of active middens/number surveyed
= A/n
= 0.6515

Optimistic:
P = number of active middens + uncertain/number surveyed
= (A + U)/n
= 0.6971

2. Next, we determine the confidence interval.

$$CI = n(1.96)\ (1/n[P(1-P)])^{1/2}\ \ (1/N(N-n))^{1/2}$$

Where:
n = original sample size before extra middens are added = 226
P = the percent of active middens calculated in part A.
N = potential population size (use larger of middens in database or 650 per Mount Graham Red Squirrel Recovery Plan)

B. The calculations for the confidence intervals are as follows (Fall 2008 data):

Estimate	n(1.96)	$(1/n[P(1-P)])^{1/2}$	$(1/N(N-n))^{1/2}$	C.I.
CI Conservative	442.96	0.0316954	0.8076556	11.34
CI Optimistic	442.96	0.0305646	0.8076556	10.93

IV. The final results are therefore:

A. Conservative:
263 +/- 11

B. Optimistic:
282 +/- 10

C. Entire range (formerly used in press release):
252 – 292

Appendix B: Pinaleño Ecosystem Restoration Project Summary

(Note: a full description of this project as described in the Final Environmental Impact Statement can be found on the Coronado National Forest's website: http://www.fs.fed.us/r3/coronado/)

All citations can be found in the Literature Cited section above.

The Safford Ranger District, Coronado National Forest, is proposing the Pinaleño Ecosystem Restoration project (PERP), located on the Pinaleño Mountains near Safford, Arizona. The 2,329-hectare (5,754-acre) project area is located in Graham County, Townships 8 and 9 South, Ranges 23 and 24 East. The treatments proposed are on approximately 1,499 hectares (3,705 acres) within the project area, and would consist of thinning dense forests, removing some standing dead trees and down woody debris, and using prescribed fire to begin restoring what was once a fire-adapted ecosystem. These treatments would be carried out over the next 10 years. The proposal balances reducing the potential for damaging wildfire with retaining the forest structure needed for wildlife. This project is designed to provide long-term protection to the endangered Mount Graham red squirrel (*Tamiasciurus hudsonicus grahamensis*) and its habitat by reducing potential for insect and disease outbreaks and damaging wildfires, in accordance with the Mount Graham Red Squirrel Recovery Plan (U.S. Fish and Wildlife Service 1993). Overall, the project is designed to improve long-term sustainability of the ecosystem and habitat for the species that depend upon it.

Background

The Pinaleño Mountains are a special place. With majestic Douglas-fir trees that are more than 700 years old, the mountains have been an important desert refuge for wildlife, Native Americans, early settlers, recreationists, and researchers. There is an increasing broad-based concern that the very attributes that make the Pinaleño's a special place are at an unacceptably high risk of loss from potential catastrophic wildfires and declining forest health, and that something urgently needs to be done to reduce the risks and scale of these types of potential losses.

The PERP has been developed over several years in response to events that have occurred in the Pinaleño Mountains. Active fire suppression and other factors over the past 100 years have drastically reduced the role of natural fire, causing the Pinaleño Mountain forests to become dense and filled with dead and down trees. These conditions have led to a very high potential for severe wildfires. In 1996 and 2004, large wildfires burned with active crown consuming fire and directly reduced red squirrel population numbers through habitat loss and mortality (Koprowski *et al*. 2006). Progressive insect infestations, beginning in 1996, began defoliating and killing trees in the spruce-fir and mixed-conifer forests. The tree mortality associated with these outbreaks has resulted in increased wildfire potential and a decline in the red squirrel population through habitat loss and decreased cone crops.

In response to these conditions, the Forest Service has worked closely with the State of Arizona Game and Fish Department and the U.S. Fish and Wildlife Service. This collaboration developed a proposed action that was distributed to the public in May, 2005. Based on public input and continued population declines of the squirrel, the planning team determined that the project is inherently tied to protection and maintenance of red squirrel habitat, and treatment design should address ways to protect and perpetuate squirrels as a primary consideration. Additional collaboration with researchers, biologists, foresters, and wildland fire management experts developed actions that meet this new focus, including the incorporation of Midden Protection Zones. This concept balances the long-term need to restore habitat for the squirrel with ensuring that no treatments will occur in currently occupied habitat considered necessary for the short-term protection of the species. The resulting proposal protects occupied habitat, reduces the potential for wildfire and insect and disease outbreaks, and manages for long-term sustainability of red squirrel habitat.

Purpose of the Project

The purpose of the PERP is to initiate forest restoration to protect the existing Mount Graham red squirrel habitat and key ecosystem components. By changing forest composition, structure, and density, the project is expected to reduce the potential for severe wildfires that could destroy red squirrel habitat. The project is also designed to reduce future insect and disease infestations, and to provide for the maturation and sustainability of future red squirrel habitat. Implementing the proposal would achieve the following goals:

- Initiate forest restoration efforts within the project area using guidelines provided in the Mount Graham Red Squirrel Recovery Plan
- Initiate the restoration of ecological processes, including the natural fire regimes (high-frequency and mixed-severity regimes)
- Improve forest health by improving the resiliency of overstory trees to insect and disease outbreaks
- Within the project area, reduce the risk of stand-replacing crown fire and its threat to the red squirrel and other important threatened and endangered wildlife habitat and forest ecosystems
- Protect or promote late-successional (old-growth) forest conditions
- Improve firefighter safety

Need for the Project

Existing Conditions

As described in previous sections, the Pinaleño Mountains are currently susceptible to wildfire, and insect and disease outbreaks, and the population of red squirrels has declined in recent years (Koprowski *et al*. 2005). Recent field observations of fuel-loading and forest stand examinations indicate that the Pinaleño forest ecosystem is characterized by a large quantity of dead trees and a dense understory of small- and medium-sized trees. Based on an inventory of stands, the project area has a high average stand density index (SDI). The SDI is an indicator of site occupancy by trees and is used as a measure of stress on trees in a stand. Tree mortality brought on from the stress of competition between individual trees for water, light, and nutrients is generally assumed to begin between 55 and 65 percent of maximum stand density, while individual tree health is best maintained when the forest densities are below 35 percent of the maximum (Lilieholm *et al*. 1994). The stands in the project area currently have a forest density averaging 73 percent of the maximum potential of a mixed-conifer forest.

Late-successional trees such as Engelmann spruce (*Picea engelmannii*), white fir (*Abies concolor*), and corkbark fir (*Abies lasiocarpa* var. *arizonica*) are now common in the understory, while many early successional tree species such as ponderosa pine (*Pinus ponderosa*) are dying in the overstory and not regenerating within the stands. The high stand densities within the mixed-conifer communities of the Pinaleño Mountains make the forest susceptible to further insect and disease outbreaks. Further, forest stand inventories show little or no regeneration of Douglas fir, a key old growth tree species and a primary food source of the Mount Graham red squirrel. The data also reveal that a greater proportion of larger trees is dying, which represents a serious long-term trend of degrading old growth forest characteristics. This loss is driven by stress from high stand densities, which were historically regulated by more frequent, mixed-severity wildfires in southwestern mixed-conifer forest ecosystems (Dieterich 1983, Graham *et al*. 1997).

The high stand densities and the amount of standing dead and down trees create a forest susceptible to uncharacteristic wildfire. In addition, insect activity and tree mortality have significantly increased in the Pinaleño Mountains in the past two decades (U.S. Forest Service 1999, 2000b, 2001, 2002, 2003, 2004, 2005). These insect outbreaks and the high-intensity fires that occurred have destroyed large areas of wildlife habitat, including critical habitat for the red squirrel (Koprowski *et al*. 2005, Merrick *et al*. 2007) and Mexican spotted owl. The fires increased the potential for soil erosion and flooding, diminished the scenic and recreational values of the forest, and damaged or destroyed public and private property.

Historical Condition

By examining the fire history of the area before European settlement, one can better understand why the vegetation structure and composition of the project area are significantly different today. Tree-ring studies conducted at Peter’s Flat and Camp Point (Grissino-Mayer *et al*. 1995) and later near Webb Peak show that widespread fires occurred frequently up until the time of European settlement, but noticeably declined thereafter. These studies also indicate that the forest consisted of stands of mixed-conifer species, primarily Douglas-fir (*Pseudotsuga menziesii*), southwestern white pine (*Pinus strobiformis*), and ponderosa pine (*Pinus ponderosa*), with inclusions of lesser amounts of white fir (*Abies concolor*), Engelmann spruce (*Picea engelmanni*), and corkbark fir (*Abies lasiocarpa* var. *arizonica*). The proposed project area historically experienced a frequent to mixed fire regime, with highly variable average fire return intervals, ranging from 3 to 60 years, depending largely upon each fire’s location on the landscape (Swetnam *et al*. 2009). The result was a complex and highly diverse landscape with a mosaic of varying vegetation patterns. Fire created more openings and aspen groves, reduced the occurrence of fire-sensitive species, removed younger age classes of trees, and minimized the accumulation of dead trees on the forest floor. Fires tended to confine Engelmann spruce and corkbark fir to riparian areas, to moist pockets of mixed-conifer stands, and to the highest elevations of the mountain.

Site-specific tree-ring data studies conducted in the Pinaleño Mountains indicated that the last widespread fires on the mountain occurred in 1879, and concluded that recent fire suppression had resulted in a current fuels buildup that is unprecedented for more than 500 years (Grissino-Mayer *et al*. 1995). This pattern of change is repeated in other mixed-conifer forest types in the Southwest (Dieterich 1983, White and Vankat 1993, Swetnam *et al*. 2001, Fulé *et al*. 2003, Sakulich and Taylor 2007). From these studies and data gathered in 1996 on the mountain, it can be concluded that far-reaching changes have occurred in forest stand densities, tree age-class distributions (shifts to smaller and younger trees), and in species composition of stands (shifts from fire-tolerant to fire-intolerant species). Similar shifts have been documented in other southwestern forests (Cooper 1960, White and Vankat 1993, Fulé *et al*. 2003, Moore *et al*. 2004).

Desired Condition

To provide optimal Mount Graham red squirrel midden and foraging habitat, the PERP includes the following desired conditions:

- Forest structure should consist of a nearly continuous multi-layered forest with overhead canopy closure greater than 80 percent.
- Basal area of live and dead trees of at least 65 m^2/ha (275 ft^2/ac) with groupings of 0.031 ha (0.078 ac) of large dominant trees greater than or equal to 40 cm (16 in) diameter at breast height (dbh) associated with greater than or equal to 5 to 8 logs and 1 to 2 standing snags greater than or equal to 40 cm (16 in) dbh (Mannan and Smith 1991).
- Snags 10 to 15 per ha (4 to 6 snags/ac) that are greater than or equal to 40 cm (16 in) dbh. Logs, as many as possible, need to be maintained, especially those in the latter stages of decay.

Habitat generally contains many but not all of the optimal characteristics, and habitat recommendations may be modified based upon results from further research and monitoring.

Conclusion and Need Statements

1. **Project Need 1:** From these observations, it is estimated that today's fuel loads and stand densities are much greater than historical forest conditions, leaving the forest increasingly vulnerable to disease, insect infestations, and fire. The ecological implications of these shifts suggest increased susceptibility to insect outbreaks and stand-replacing fires (Dieterich 1983, White and Vankat 1993, Fulé *et al*. 2004, Moore *et al*. 2004).

Therefore, **there is a need to initiate a restoration effort that seeks to recover ecological processes and treat the causes of declining ecosystem health by reducing stand densities, changing understory species composition, and reducing fuel loading**. The restoration approach seeks to trend forests toward a condition that is self-sustaining and compatible with the conditions under which they naturally evolved (Friederici 2003), employing a strategy emphasizing ecological functions and processes (Falk 2006).

2. **Project Need 2:** The main threats to the Mount Graham red squirrel are habitat loss and catastrophic wildfire. Over the past 20 years, a significant portion of previously occupied red squirrel habitat has been rendered unsuitable due to insect outbreaks and fire (Koprowski 2005d,

Koprowski *et al*. 2005, Koprowski *et al*. 2006). Associated with this reduction in habitat, there is an accompanying decline in population size; the current conservative population estimate is 250 squirrels (AGFD 2009, unpublished data). As such, the remaining habitat, most of which falls within the project area, is of high importance.

Therefore, **a need exists to protect red squirrel habitat within the project area from losses due to fire, insect outbreaks, and diseases, and to restore areas of degraded habitat for this subspecies**.

All actions include resource-specific design criteria that guide the manner in which the actions are implemented to minimize or reduce anticipated effects. The entire project is expected to take 10 years to complete.

Appendix C: Protocol for Monitoring Habitat and Areas Under Management to Become Habitat

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MAPPING AND MONITORING MT. GRAHAM RED SQUIRREL HABITAT WITH GIS AND THEMATIC MAPPER IMAGERY

James R. Hatten

To estimate the Mt. Graham red squirrel (MGRS) population, personnel visit a proportion of middens each year to determine their occupancy (Snow 2009). The method results in very tight confidence intervals (high precision), but the accuracy of the population estimate is dependent upon knowing where all the middens are located. I hypothesized that there might be areas outside the survey boundary that contained Mt. Graham red squirrel middens, but the ruggedness of the Pinaleño Mountains made mountain-wide surveys difficult. Therefore, I started exploring development of a spatially explicit (geographic information system [GIS]-based) habitat model in 1998 that could identify MGRS habitat remotely with satellite imagery and a GIS. A GIS-based model would also allow us to assess changes in MGRS habitat between 2 time periods because Landsat passes over the same location every 16 days, imaging the earth in 185 km swaths (Aronoff 1989). Specifically, the objectives of this analysis were to (1) develop a pattern recognition model for MGRS habitat, (2) map potential (predicted/modeled) MGRS habitat, (3) identify changes in potential MGRS habitat between 1993 and 2003, and (4) evaluate the current location of the MGRS survey boundary.

STUDY AREA

The Pinaleño Mountains trend northwest to southeast for approximately 35 km, are less than 20-km wide, and have an extensive high-elevation plateau, reaching a height of 3,268 m. There are 4,097 ha of terrain above the 2,744 m contour, and 538 ha above the 3,049 m contour, supporting one of the southernmost spruce-fir forests in North America. The northwest/southeast orientation of the Pinaleño Mountains creates aspects that generally face northeast or southwest, creating temperature differences that influence the distribution of plants and animals. The topography inside the MGRS survey boundary is gentle compared to the steep slopes that fall sharply away from the upper plateau.

METHODS

Modeling Overview

I used the Arizona Game and Fish Department (AGFD) MGRS midden database for model development because it contained >1,000 midden locations collected over a 15-year period. To increase spatial and model accuracies, I used only sites that were spatially referenced with a global positioning system (GPS), with horizontal accuracy varying between 5 and 20 m. The AGFD midden database also contained habitat information collected at hundreds of sites (e.g.

mixed conifer, ecotone, spruce-fir). I extracted all other variables used in the characterization of MGRS habitat from TM (Thematic Mapper) imagery and a digital elevation model (DEM).

I completed 7 steps to develop and test a spatially explicit habitat suitability model. First, I created a boundary for the GIS analysis by masking (excluding) vegetation communities (e.g. oak grasslands, upper Sonoran Desert) that do not provide the structural characteristics necessary to support MGRS habitat. Second, I classified a Landsat TM 1993 image of the unmasked portion of the Pinaleño Mountains. Third, I identified spectrally suitable and unsuitable areas by overlaying 50 percent of the MGRS midden locations and the classified TM image with a GIS. Fourth, I conducted an accuracy assessment inside the MGRS survey boundary to determine the accuracy of the classified image by overlaying the remaining midden locations not used in model development. Fifth, I identified potential MGRS habitat outside the survey boundary by overlaying the MGRS survey boundary on predicted MGRS habitat. Sixth, MGRS biologists inspected randomly selected sites to determine the suitability of predicted MGRS habitat outside the survey boundary. Seventh, I conducted change detection by comparing classified TM imagery from 1993, 1997, and 2003.

Topographic Analysis

I created a continuous elevation surface of the Pinaleño Mountains with U.S. Geological Survey DEMs (30 m resolution). I extracted slope, elevation, and aspect data from the DEMs with GRID functions (ESRI 1992) and aggregated them into discrete classes. Elevation data were aggregated into 13, 76-m (~250 ft.) classes; slope data were aggregated into 4 classes (0-10º, 11-20º, 21-30º, and >30º); and aspect data into 4 classes (north [315 - 45º], east [46 - 135º], south [136 - 225º], and west [225 - 314º]. I generated midden frequencies with a GIS by overlaying topographic classes and midden data.

Spectral Analysis

I characterized the spectral properties of the Pinaleño Mountains with a TM image acquired on June 19, 1993. The TM image had a pixel resolution (ground sample distance) of 28.5 m, contained seven spectral bands, and had ~30 m horizontal accuracy. I used bands 1-5, which correspond to blue, green, red, near infrared (IR), and mid IR portions of the electromagnetic spectrum (Avery and Berlin 1992). ERDAS IMAGINE software (ERDAS Inc., Atlanta, Georgia) was used for all image-processing tasks, and ArcInfo software (ESRI Inc., Redlands, CA) was used for all GIS analysis. I created an additional composite band for image classification by calculating the Normalized Difference Vegetation Index (NDVI = [band 4 - band 3 / band 4 + band 3]) because of its proven utility in discriminating differences in vegetation density and biomass (Jensen 1983) and for minimizing shadow effects.

I characterized the spectral properties of the forest canopy with pattern recognition, a clustering algorithm that finds patterns in spectral data that can be extracted through classification (Schrader and Pouncey 1997). Before conducting the classification, I created a vegetation-density grid of the Pinaleño Mountains by calculating NDVI from TM imagery. The NDVI ranged from –0.50 to 0.75, with smaller NDVI values having less density and/or biomass than higher values (Avery and Berlin 1992). I identified an approximate NDVI cutpoint between coniferous forests and desert scrub vegetation at 0.45, as determined from the vegetation-density grid, and masked areas <0.45 (NDVI) because they did not contain MGRS middens. I then used the spectral information contained in TM bands 1-5, plus NDVI, to divide the unmasked conifer forests into 12 spectral classes with the ISODATA (iterative, self-organizing data analysis) algorithm (Tou and Gonzalez 1974).

To characterize spectral and structural properties of the forest canopy occupied by MGRS, I randomly selected 50 percent of the midden locations (511). The remaining middens (507) were used later in accuracy assessment. Identifying spectral areas occupied by MGRS was an iterative process. Midden data were overlaid on the 12 spectral classes and the resultant frequencies examined. Spectral classes that contained relatively few middens (<5 percent) were collapsed into a single unsuitable class, while the remaining classes were considered spectrally suitable. There were no criteria to guide this process of spectral class clumping, just careful examination of the midden data overlaid on the imagery. Next, I used the habitat data that had been collected at the midden locations to characterize the forest composition within each spectral class. If the spectral classes contained two or more habitat types, they were candidates for collapsing (merging) with other mixed classes in an effort to create the most effective, simple model. I used ancillary topographic data (slope, aspect, and elevation) in conjunction with pattern recognition to provide insight into the distribution of MGRS middens.

Accuracy Assessment

I conducted accuracy assessment in 3 areas: (1) predicted MGRS habitat within the survey boundary, (2) predicted (modeled) unsuitable areas within the survey boundary, and (3) predicted MGRS habitat outside the survey boundary. While I had a great deal of validation data within the survey boundary (middens), virtually no data existed outside the survey boundary. To assess model accuracy, I overlaid 507 randomly selected middens – the middens not used in model development – on the final classified image. Accuracy was calculated by errors of omission or the number of middens that fell outside of predicted MGRS habitat (Story and Congalton 1986). Using middens to determine model accuracy was convenient because it eliminated the difficulty of identifying MGRS habitat, for which I had no proven set of criteria. I examined the accuracy of the unsuitable class, as determined from the model, by visiting 18 randomly selected sites located within meadows, burn areas, rock outcrops or pine/oak/aspen thickets. Field notes were collected to aid in interpreting classification error.

To determine whether predicted MGRS habitat outside the survey boundary was actually suitable, MGRS biologists visited 17 randomly selected locations. Data were collected at each random point on elevation, slope, aspect, seral stage, site potential, evidence of squirrel presence, and tree species. Seral stage was denoted as pole (young trees), mature, old growth, and mixed ages. A qualitative habitat suitability ranking was developed by MGRS personnel and assigned to each site visited: (1) low = little to no potential, (2) moderate = habitat did not look too unsuitable and probably could support squirrels, and (3) high = very good habitat or squirrels seen or heard. Qualitative habitat criteria included presence or absence of standing snags or downed logs, canopy density, site lushness, presence of large cone-bearing trees, slope, and aspect.

Lively discussions ensued at each random site between MGRS biologists as to whether it constituted MGRS habitat or not. In the strictest sense, any area that was mixed conifer, ecotone, or spruce-fir qualified as suitable because those habitat types contained MGRS middens within the survey boundary. However, a lack of fine-scaled habitat criteria made ranking habitat potential outside the survey boundary difficult and somewhat qualitative. Sites where MGRS were seen or heard were considered suitable, but sites without evidence of MGRS required a judgment call on habitat suitability.

Change Detection

To examine changes in MGRS habitat in the Pinaleño Mountains, I acquired TM imagery from 1993, 1997, and 2003. Because I was interested in changes to MGRS habitat, I used the 1993 TM image as a base-line image to which I compared the other 2 images. While all three images were acquired during the summer months (June - August), small differences in the solar illumination angle could interfere with the change detection, so I adjusted the tonal qualities of the 1997 and 2003 images to match the 1993 image with histogram matching (Schrader and Pouncey 1997). Once the images were tonally matched, I calculated NDVI for each time period (12 classes) and used pixel (digital number) subtraction to identify areas where NDVI had decreased. To minimize change-detection error, I only considered pixels that had increased or decreased by at least two NDVI classes. A field reconnaissance in 2000 into burn areas from the 1996 Clark Peak fire found that NDVI was an effective metric to monitor changes in the forest canopy.

Survey Boundary Analysis

To ascertain whether the MGRS survey boundary was accurately placed, I overlaid midden and topographic data (slope, aspect, elevation) to characterize surrounding terrain features occupied by MGRS. Aspect and elevation were examined together because they both regulate vegetation and microclimatic variables such as temperature, relative humidity and tree species. I also examined whether the northwest/southeast trend in the Pinaleño Mountains had an impact on midden distribution within similar elevation and aspect classes, but on opposite sides of the Pinaleño backbone.

RESULTS

Topographic Analysis

Middens were sparse between 2,286 m and 2,743 m (fig. 12.1A), with no middens observed on southward slopes below 2,743 m, and none observed on westward slopes below 2,670 m. The lowest elevation at which a midden was observed was 2,353 m, in the Turkey Flat survey unit, found on a north aspect with a gentle slope (<10º). Midden concentrations increased above 2,743 m and extended all the way to the top of Mount Graham (3,268 m). Concerning aspect (fig. 12.1B), the north slopes of the mountain contained the greatest number of middens, east and west slopes contained similar numbers of middens, and southerly aspects the fewest. Regarding slope (fig. 12.1C), classes 1-2 (0-20º) had the most middens, with a rapid drop in midden frequency in slope classes 3 and 4. Very few middens were observed over 30º and none over

40º. To refine the GIS analysis, I created a GIS layer that divided the Pinaleños into two zones: (1) within the survey boundary (zone 1), and (2) outside the survey boundary above 2,353 m elevation (zone 2).

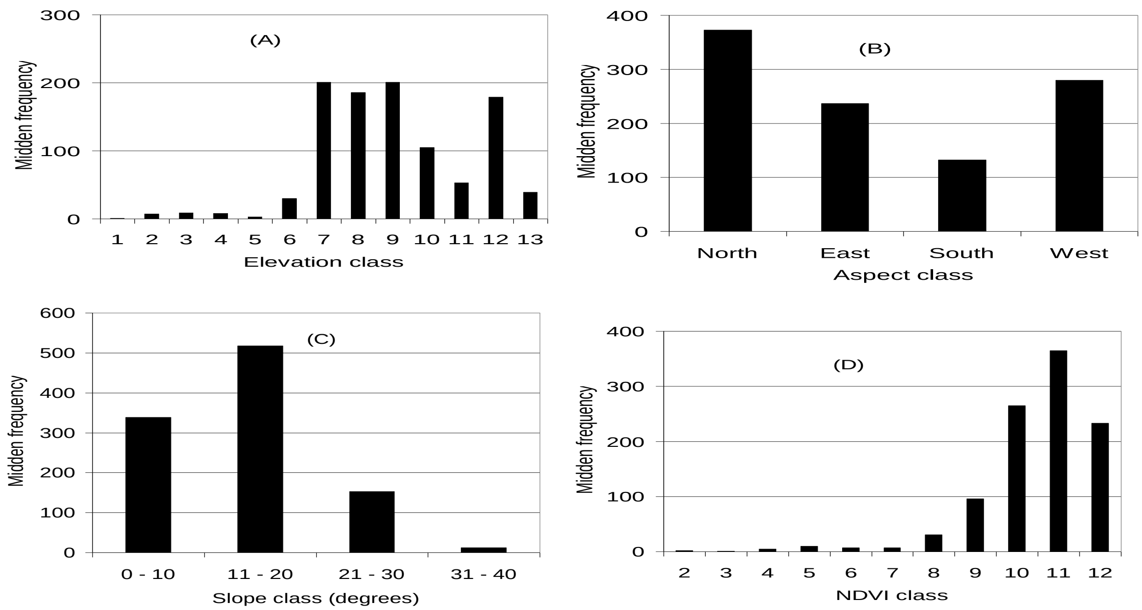

Figure 12.1. Relationships among the topographic variables (elevation, aspect, and slope), NDVI, and middens. Elevations (Figure 12.1A) are divided into 13 consecutive 76 m (250 ft) elevation bands; class 1 starts at 2,286 m, and class 13 starts at 3,200 m.

Spectral Analysis

Relatively few middens (8.3 percent) were observed below NDVI class 8 (NDVI raw value < 0.45) and several field trips helped qualitatively define the contents of the NDVI classes. Classes 1-3 contained rock outcrops, semi-desert grassland, meadows, water features, and bare soils. In contrast, classes 4-7 contained oak woodlands, pinyon-juniper, and pine-oak communities, while classes 8-12 corresponded with mixed conifer, ecotone, and spruce-fir habitats commonly associated with MGRS. Since NDVI classes <8 were unsuitable for MGRS, I masked them out of all subsequent image analyses (fig. 12.1D).

Spectral classes 1-6 contained 91 percent of the middens (457) and classes 7 - 12 contained 9 percent (50). A close inspection of the middens, when overlaid on the unclassified TM image, revealed that the majority of middens in classes 7-12 were found along the edges of features, such as roads and meadows (spectrally confused areas). Thus, spectral classes 7-12 were aggregated into a single class and labeled unsuitable for MGRS.

Class 1 was the only spectral class comprised of a relatively pure habitat type (88.5 percent spruce-fir). The other five spectral classes had substantial mixing of two or more habitat types. Due to habitat mixing, I simplified the model by aggregating spectral classes 1-6 into a single spectral class that I referred to as potential or predicted MGRS habitat.

Accuracy Assessment

Classification accuracy of the suitable class (as determined from errors of omission) was 93 percent inside the survey boundary, and 83 percent for the unsuitable class. Close examination of the unclassified TM imagery revealed that most classification errors appeared related to spatial (positional) error because their locations were less than 1 pixel (28.5 m) from a feature edge, such as a meadow or forest boundary. Such areas often had two or more features represented (covered) by a single 28.5 X 28.5 m (0.08 ha) pixel and were spectrally mixed.

All but 1 of the 17 random points MGRS biologists visited outside the survey boundary, but within the suitable class, contained Douglas-fir. The other site was located at an elevation of 3,085 m, had a north aspect, and contained subalpine fir and Engelmann spruce. Thus, the GIS-based model worked inasmuch as it identified potential MGRS habitat, but seral stage and aspect reduced the habitat potential at some sites. Four of the 17 sites (2 northward and 2 eastward sites) contained good or moderate habitat, with MGRS seen or heard at 2 sites. The ground slopes of the moderate-to-good habitats were between 20-45º and contained old-growth or mixed-age forest. Two of the sites were located at a relatively low elevation (2,515 m), and adult red squirrels were observed clipping cones from Engelmann spruce. While no middens were observed outside the survey boundary, MGRS feeding and foraging suggested that middens were probably in the immediate vicinity.

To determine the suitability of predicted MGRS habitat outside the survey boundary, MGRS staff inspected eight sites outside the survey boundary with southward or westward aspects. All 8 sites had low-quality MGRS habitat and no MGRS were seen or heard. There was Douglas-fir or white fir at every site, but the overall quality of the habitat appeared low. Generally, the sites tended to be quite open, steep, hot, and had few quality snags or large downed logs. Also, the south and westward slopes appeared to be less lush compared to the randomly selected sites on the north and east slopes at comparable elevations outside the survey boundary. The GIS-based model appeared to delineate the coniferous vegetation well, with oak thickets and other unsuitable vegetation being excluded. All of the sites had components necessary to be classified as mixed conifer, but some also had isolated pine and oak scattered throughout. Thus, many of the southward- and westward-facing sites were transitional vegetation communities that made a clear-cut classification difficult.

Change Detection Analysis: 1993 to 2003

Potential MGRS habitat, as determined from the pattern recognition model, declined 8.0 percent between 1993 and 2003 (fig. 12.2). In 1993, there were 3,769 ha of potential MGRS habitat, which decreased by 3.2 percent in 1997, and by another 4.8 percent by 2003. The Clark Peak fire of 1996 was clearly responsible for the decline in potential MGRS habitat between 1993 and 1997. In contrast, the decline of potential MGRS habitat between 1997 and 2003 was largely due to insect damage in the spruce-fir forest.

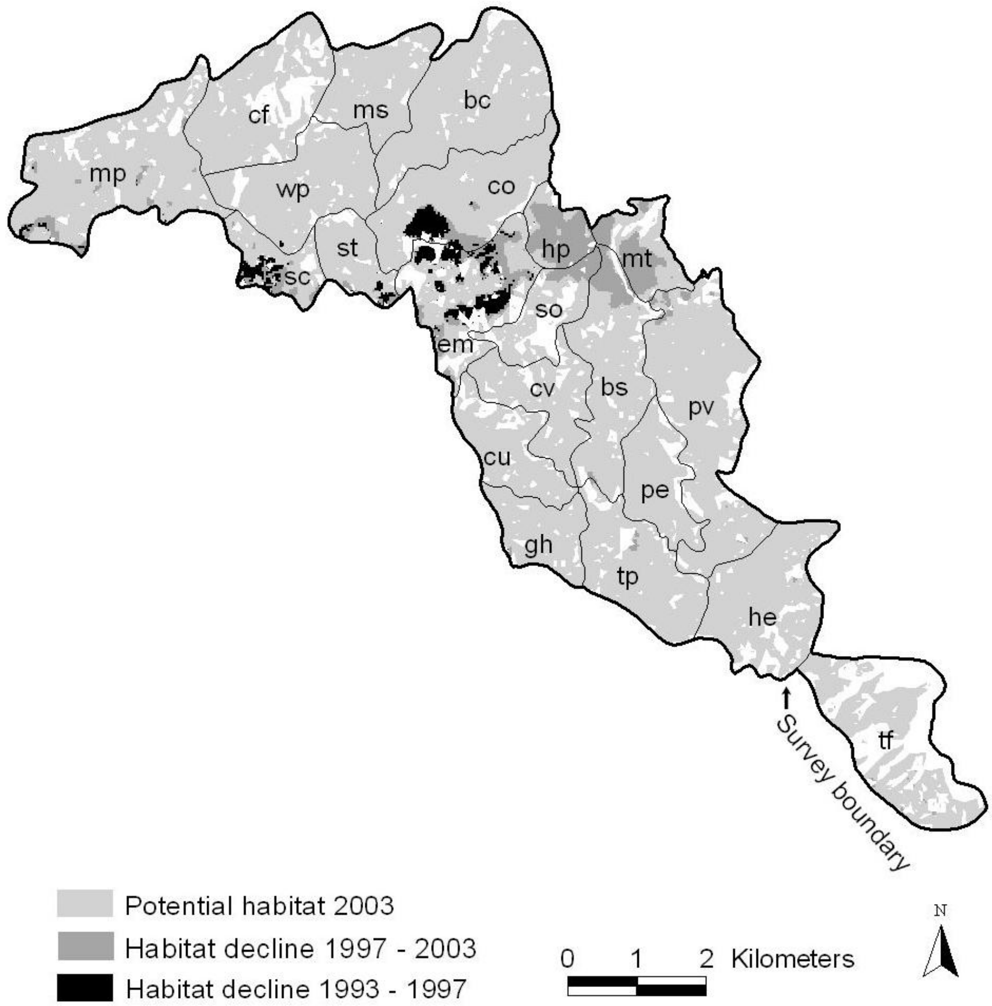

Figure 12.2. Changes in potential MGRS habitat inside the survey boundary are displayed between 1993, 1997, and 2003. Potential MGRS habitat was determined with pattern recognition and GIS for these three time periods. Potential refers to spectral properties of the forest canopy and not to microhabitat features that the squirrels might select for.

Survey Boundary

Middens were detected at different elevations according to aspect, and their frequency of occurrence was inversely related to the lower-elevation bounds at which they were first detected. Midden occurrence, by elevation, differed within the four aspect classes depending on which side of the Pinaleño backbone (NW/SE axis) they were located. Middens that were on the NE side of the backbone were found much lower on northward- or eastward-facing slopes when compared with the SW side of the backbone. This pattern was true for middens found on westward-facing slopes as well, but the difference was not as pronounced as the northward/eastward slopes. In contrast, the southern slopes, regardless of their orientation to the backbone, contained middens at similar elevations.

Based upon the topographic analysis, I temporarily adjusted the survey boundary on the NE side of the Pinaleño backbone to the 2,353 m contour and identified all potential MGRS habitat within Zone 2 (fig. 12.3). This resulted in 1,596 ha of potential MGRS habitat that has had few or no surveys, areas that might contain middens.

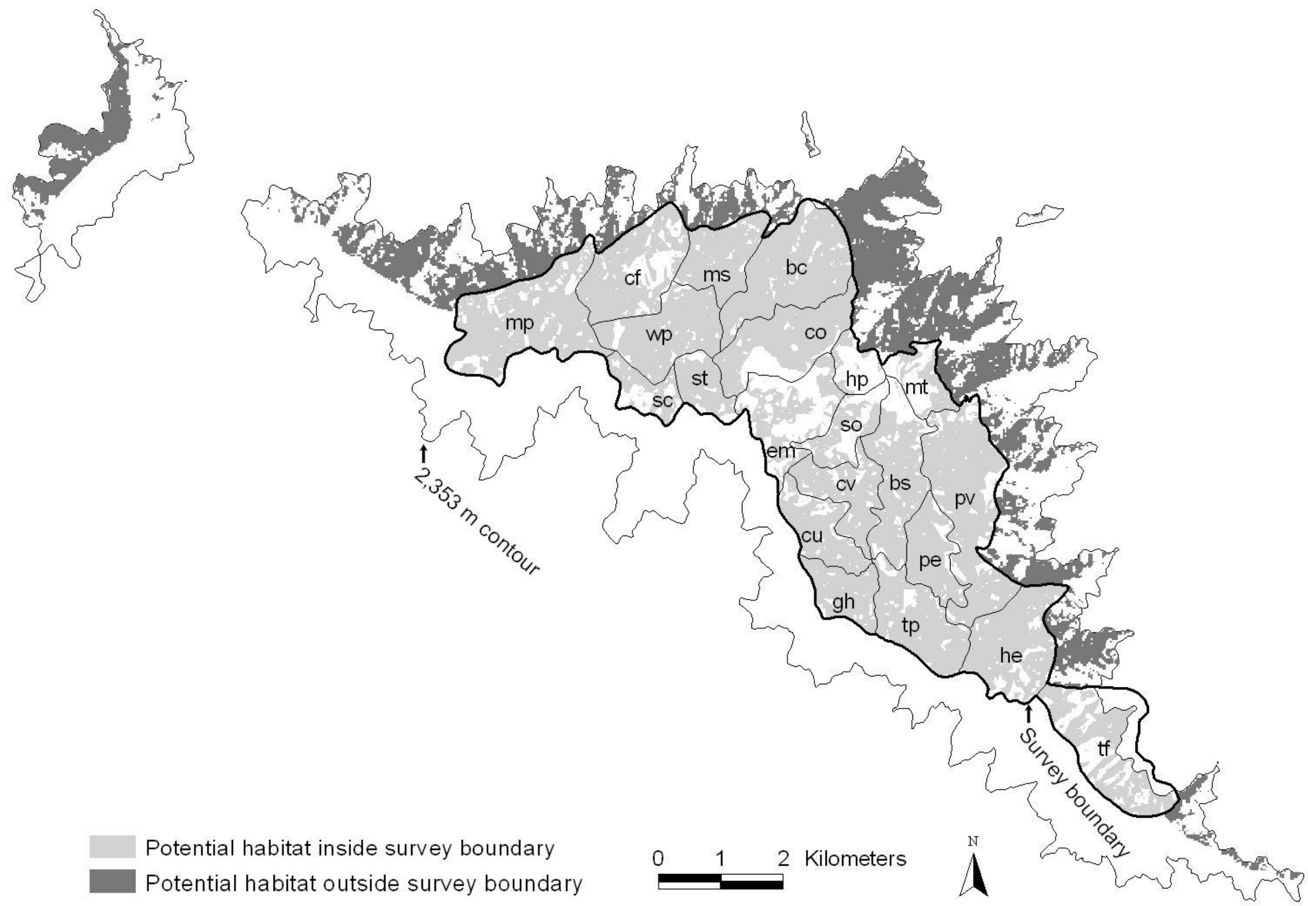

Figure 12.3. Potential MGRS habitat, determined from a pattern recognition model, within the survey boundary and within zone 2 – the area between the 2,353 m contour (the lowest elevation that MGRS were observed) and the current survey boundary.

DISCUSSION

Topographic Analysis

Elevation, temperature, and aspect are important factors in the formation of biotic communities in the Southwest (Merriam and Steineger 1890; Brown 1994), and this is especially apparent in the Pinaleño Mountains. The fact that MGRS middens occurred at different elevations, according to aspect, is consistent with the life zone (biome) concept. Slopes that face eastward or northward are cooler and moister than southward- or westward-facing slopes and result in mixed-conifer forests occurring at lower elevations. The influence of slope on MGRS placement is less clear because many of the steeper northern and eastward slopes (>30º) on Mt. Graham have not been searched. These steeper slopes present difficulties and dangers to MGRS surveyors and will not likely be searched systematically or repeatedly.

Spectral Analysis and Accuracy Assessment

The MGRS pattern recognition model is a simple tool for identifying MGRS habitat based upon spectral and structural characteristics of the forest canopy and should be useful as long as TM imagery is available. The close agreement between my MGRS habitat estimate and an earlier estimate (USFS 1988) provided an independent check of the pattern recognition model.

It would benefit MGRS managers if additional GIS-based models were developed to monitor specific habitat types (e.g. mixed-conifer, ecotone, spruce-fir) or to rank the quality of MGRS habitat. The pattern recognition model presented in this paper cannot be used to monitor changes in the three habitat types effectively because the spectral classes were collapsed into a single class. Of the six spectral classes found suitable, only class 1 contained a relatively pure habitat type (88.5 percent spruce-fir). It is probable that higher-resolution satellite imagery now commonly available might improve model performance by reducing spectral confusion that resulted when two or more features (e.g. trees, boundaries) occurred within a single image cell. Higher-resolution imagery would also reduce omission errors that resulted when MGRS middens were <30m from the edge of the forest, resulting in spectral confusion.

Another weakness of the MGRS pattern recognition model is that it has no statistical equation that can rank the probability or quality of MGRS habitat. A logistic regression approach to modeling (Hosmer and Lemeshow 1989) similar to that taken by Pereira and Itami (1991) might provide a more robust model for assessing MGRS habitat. I did not attempt logistic regression modeling because accurate records have not been kept for all areas that have been searched for middens. However, for the purpose of logistic regression modeling, a subset of MGRS middens could be extracted from the AGFD midden database from areas where complete surveys have occurred. This subset would not include the most rugged areas of the Pinaleño Mountains, but it would include many of the survey units within the current survey boundary.

Change Detection

Potential MGRS habitat declined significantly between 1993 and 2003, raising concerns about the stability of their habitat. The decrease between 1993 and 1997 was attributable almost exclusively to the Clark Peak fire of 1996, while the decline between 1997 and 2003 was related to insect damage in the spruce-fir habitat zone. The full impact of the spruce-fir insect infestation was not evident in 2003 when the latest change-detection work was done. Since then, additional declines in MGRS habitat have occurred from insects, and a large fire occurred in 2004. It would benefit MGRS managers if the quantity of MGRS habitat were assessed annually or biannually. Remote sensing coupled with a GIS appears to be a promising tool that can assist managers in monitoring the amount and health of MGRS habitat over time.

Survey Boundary

There is evidence to support lowering the survey boundary on the NE ramparts of the Pinaleños to 2,353 m (the lowest elevation at which a midden was observed). Middens were found noticeably lower on the NE side of the Pinaleños' backbone (NE/SW axis), particularly on northward- and eastward-facing slopes. In contrast, there was little evidence to support substantially altering the survey boundary on the SW side of the Pinaleño backbone, where MGRS habitat appeared marginal outside the survey boundary. Zone 2 was significant in our analysis because it corresponded to an elevation zone (>2,353 m) where middens have been located near Turkey Flat, but much of the current survey boundary skirts above 2,353 m. Thus, most of the potential habitat within Zone 2 has never been surveyed and remains undocumented. It stands to reason that if the survey boundary were lowered, more middens would be discovered on similar facing slopes. Potential MGRS habitat identified by the pattern recognition model can be used to locate new survey areas outside the survey boundary: areas like West Peak, Ladybug Peak, and Mt. Graham.

Population Estimates

It is important that managers have access to the most accurate information when calculating the MGRS population. Based upon our analysis, I conclude that not all MGRS middens have been accounted for in the last decade, and until the survey boundary is modified and the entire area searched, this situation will continue. Fortunately, it appears that the population has been underestimated by some fraction, meaning that the current population estimates are conservative. Given the decline in MGRS habitat over the last decade, it will become increasingly important to identify all potential MGRS habitat and to revise the population estimates as appropriate.

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Appendix D: Climate Change Vulnerability Assessment

This vulnerability assessment was conducted using the process described in U.S. Environmental Protection Agency (2009). A frame work for categorizing the relative vulnerability of threatened and endangered species to climate change. National Center for Environmental Assessement, Washington, D.C.;EPA/600/R-09/-011. Available from the National Technical Information Service, Springfield, V.A. and online at http://www.epa.gov/neca. Results of this Mount Graham red squirrel climate vulnerability assessment have been recently published and are freely available on line at http://www.treesearch.fs.fed.us/pubs/37406 in the following document: Glick, P., B.A. Stein, and N.A. Edelson, editors. 2011. Scanning the conservation horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C. 168pp.

Baseline Vulnerabilities (Vb) of the Mount Graham Red Squirrel

1) Current population size		Score
<100	1	
100-500	2	2
500-1,000	3	
1,000-10,000	4	
10,000-50,000	5	
>50,000	6	

Certainty:		
	high (3)	
	medium (2)	3
	low (1)	

2) Population trend in the last 50 years		Score
>80% reduction	1	
>50% reduction	2	
>20% reduction	3	
apparently stable	4	4
increasing	5	

Certainty:		
	high (3)	
	medium (2)	2
	low (1)	

3) Current population trend		Score
rapid decline	1	
slow decline	2	
stable	3	3
increasing	4	

Certainty:		
	high (3)	
	medium (2)	2
	low (1)	

4) Range trend in the last 50 years		Score
>80% reduction	1	
>50% reduction	2	2
>20% reduction	3	
apparently stable	4	
increasing	5	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

5) Current range trend		Score
rapid decline	1	
slow decline	2	2
stable	3	
increasing	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

6) Likely future non-climate stressor trends		Score
increase	1	
stable	2	2
reduction	3	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

7) Replacement time for individuals		Score
>5 years	1	
2-5 years	2	2
<2 years	3	
<1 year	4	

Certainty:	high (3)	
	medium (2)	3
	low (1)	

8) Likely future vulnerability to stochastic events		Score
highly vulnerable	1	1
vulnerable	2	
not vulnerable	3	
benefitting	4	

Certainty:	high (3)		
	medium (2)		3
	low (1)		

9) Likely future vulnerability to future policy or management changes		Score
highly vulnerable	1	1
vulnerable	2	
not vulnerable	3	
benefitting	4	

Certainty:	high (3)	
	medium (2)	3
	low (1)	

10) Likely future vulnerability to natural stressors		Score
highly vulnerable	1	
vulnerable	2	2
not vulnerable	3	

Certainty:	high (3)	
	medium (2)	1
	low (1)	

Total score:	**23**
Cumulative certainty score:	**23**

Baseline vulnerability scores:

Vb1	<18	Critically vulnerable
Vb2	18-25	Highly vulnerable
Vb3	26-33	Less vulnerable
Vb4	>33	Least vulnerable

SPECIES SCORE: **Vb2** **Highly vulnerable**

Climate Change Vulnerabilities (Vc) of the Mount Graham Red Squirrel

1) Physiological vulnerability to temperature increase		Score
likely highly sensitive	1	
likely moderately sensitive	2	2
likely insensitive	3	
likely to benefit	4	

Certainty:	high (3)	
	medium (2)	2
	low (1)	

2) Physiological vulnerability to precipitation change		Score
likely highly sensitive	1	
likely moderately sensitive	2	2
likely insensitive	3	
likely to benefit	4	

Certainty:		
	high (3)	
	medium (2)	2
	low (1)	

3) Vulnerability to change in frequency/degree of extreme weather events		Score
likely highly sensitive	1	1
likely moderately sensitive	2	
likely insensitive	3	
likely to benefit	4	

Certainty:		
	high (3)	
	medium (2)	2
	low (1)	

4) Dispersive capability		Score
low	1	1
moderate	2	
high	3	

Certainty:		
	high (3)	
	medium (2)	3
	low (1)	

5) Degree of habitat specialization		Score
highly specialized	1	1
moderately specialized	2	
generalist	3	

Certainty:		
	high (3)	
	medium (2)	3
	low (1)	

6) Likely extent of habitat loss due to climate change		Score
all or most (>50%)	1	
some (20-50%)	2	2
no change	3	
some gain (20-50%)	4	
large gain (>50%)	5	

Certainty:		
	high (3)	
	medium (2)	2
	low (1)	

7) Ability of habitats to shift at same rate as species			Score
highly unlikely		1	1
unlikely		2	
likely		3	
Certainty:	high (3)		
	medium (2)		3
	low (1)		
8) Availability of habitat within new range			Score
none		1	1
limited extent		2	
large extent		3	
Certainty:	high (3)		
	medium (2)		3
	low (1)		
9) Dependence on temporal inter-relations			Score
highly dependent		1	
moderately dependent		2	
independent		3	3
Certainty:	high (3)		
	medium (2)		2
	low (1)		
10) Dependence on other species			Score
highly dependent		1	
moderately dependent		2	
independent		3	3
Certainty:	high (3)		
	medium (2)		2
	low (1)		

Total score: **17**
Cumulative certainty score: **24**

Climate change vulnerability score:

Vc1	<16	Critically vulnerable
Vc2	17-22	Highly vulnerable
Vc3	23-27	Less vulnerable
Vc4	28-32	Least vulnerable
Vc5	>32	Likely to benefit

SPECIES SCORE: **Vc2** **Highly vulnerable**

Combining Baseline and Climate Vulnerability Scores into Overall Vulnerability Score (Vo) for the Mount Graham Red Squirrel

	Vb1	Vb2	Vb3	Vb4
Vc1	Vo1	Vo1	Vo2	Vo3
Vc2	Vo1	**Vo1**	Vo2	Vo3
Vc3	Vo1	Vo2	Vo3	Vo4
Vc4	Vo1	Vo2	Vo3	Vo4
Vc5	Vo2	Vo3	Vo4	Vo4

Vo1	Critically vulnerable
Vo2	Highly vulnerable
Vo3	Less vulnerable
Vo4	Least vulnerable

SPECIES SCORE: **Vo1** **Critically vulnerable**

Certainty/Uncertainty Analysis for the Mount Graham Red Squirrel

Total score	Certainty evaluation
20-32	Low
33-45	Medium
>45	High

	Vb	Vc	Both
Total score	23	24	47

CERTAINTY SCORE: **High**